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# JOURNAL

OF THE

# AMERICAN WATER WORKS ASSOCIATION

VOL. 17 FEBRUARY, 1927 No. 2

CONTENTS

# PRETREATMENT OF BOILER FEEDWATER

## Progress Report of Sub-Committee No. 2 on Water Softening by Chemicals (External Treatment)[1]

By Clarence R. Knowles, *Chairman*

The following subjects were assigned to Sub-Committee No. 2 for investigation and report:

1. The chemical reactions to be considered in the light of present knowledge of physical chemistry, with special attention to the hydrogen-ion concentration of water and its influence upon the precipitation of hardening salts.
2. Compilation of operating data to determine the relative value of continuous and intermittent softeners.
3. Collection of operating figures showing the efficiency of subsidence tanks and basins in order to be able to submit recommendations for the more efficient design of basins for precipitation of solids and the removal of sludge.
4. The causes and prevention of retarded chemical reaction.
5. Standardization of rates of filtration employed for the removal of suspended solids from softened water.

[1] The personnel of Sub-Committee No. 2, on Water Softening by Chemicals (External Treatment), of the Joint Research Committee on Boiler-Feedwater Studies is as follows:

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6. The effect of siliceous material as a filtering material when used in conjunction with hot chemical softeners, and the value of non-siliceous filtering material.

7. A consideration of the economic value of lime-soda softener treatment preliminary to zeolite softeners or to evaporators.

8. Standardization of nomenclature employed in the field of softening of water by chemicals and of the apparatus and appurtenances in use in these systems.

Your Committee presents reports on the above subjects as follows:

Study A: Report on the relative value of continuous and intermittent water softeners.

Study B: Report on the economic value of lime-soda softening preliminary to zeolite softening.

Study C: Report on the economic value of lime-soda softening preliminary to evaporators.

## STUDY A. OPERATION OF CONTINUOUS AND INTERMITTENT LIME-SODA WATER-SOFTENING PLANTS

The investigation of this subject has necessarily been broadened somewhat to include a study of the typical equipment employed in each type of softening plant, in view of the intimate relation existing between the installation and operation in both cases. As any manufacturer of water-purification equipment may build either the continuous or intermittent type of apparatus, subject only to the limitations of his technical knowledge and engineering skill, it was felt that an impartial study of this important angle of the problem could be made.

A typical continuous softener, as its name implies, provides for the continuous treatment, settling, and filtration of a water at either a constant or variable rate of flow through the apparatus. Ordinarily the retention period provided is four hours, with the softener running at its full rated capacity, although in some cases this has been decreased slightly and in others has been materially increased.

The typical intermittent softening plant comprises two or more tanks which are filled, treated, and emptied by the batch method, together of course with the necessary auxiliary equipment. In this case, also, the minimum time for which each tank is in service is 4 hours; but in this case a half-hour is provided for filling the tank, a minimum of 2½ hours for settling, and 1 hour for emptying. The

service period of each tank and the number of tanks are frequently increased.

*Comparison of Equipment*

*Size of reaction and settling tank.* The typical intermittent plant requires a total tankage of at least 50 per cent more than the continuous plant, and usually requires at least twice as much floor space.

*Storage.* Since a tank of the intermittent plant must be emptied rapidly, in order not to waste the settling capacity of the tank, provision is generally made to accomplish this emptying in not more than an hour. The treated water is discharged through filters into a clear-well with a capacity usually equal to one and one-half to two hours normal water consumption, or more.

Obviously the continuous softening plant does not require storage of this sort, since it is delivering treated and filtered water uninterruptedly and can meet the demand as it occurs.

*Filters.* Assuming that an intermittent tank holds a four-hour supply of water and is emptied in one hour, it is obvious that considerably greater filter capacity must be provided than for the continuous softener in which the same total quantity of water is distributed over a four-hour period.

*Pumps.* If pumping of the raw-water supply to the softener is necessary, the intermittent plant will require pumps with about four times the capacity of those needed for the continuous plant, since the volume of water pumped into one of the intermittent tanks in an hour is distributed in the case of the continuous plant over a four-hour period. Much of this head is lost in the case of the intermittent plant due to the decreasing head as the tank is drained. In the continuous plant, with a draw-off of the treated water at the top of the tank, the head is retained in large measure.

*Mixing chemicals with water being softened.* In the continuous type of apparatus, where a relatively small amount of water is being treated at any given moment, it is not particularly difficult to secure good mixing of the chemicals with the waters being softened. In the intermittent system, in which the entire tank supply is treated at once, special provision must be made for the distribution of the chemical reagents throughout the large mass of water being treated. In small plants mechanical stirrers may be employed. In larger plants, compressed air is usually the agent employed for agitation, a compressor and auxiliaries thus becoming an essential unit in this type of plant.

*Initial cost.* The initial cost of an intermittent plant, installed, of reasonably large size, to meet the requirements of boiler-feed-water purification, will average from about 30 to 50 per cent more than for a continuous plant of the same hourly capacity. The difference in the overhead expense of the two plants thus becomes an item of importance in considering the operation of the apparatus.

*Comparison of operation*

*Cost of chemicals.* The amount of chemicals required in either case is approximately the same. It is standard practice in the case of the intermittent plant to employ a coagulant, usually sulphate of iron, in addition to the lime and soda required for treatment. The use of a coagulant is not standard practice with all continuous plants, but the evidence in many cases indicates that the improvement in results of the water treatment in such cases effected by the use of a coagulant is sufficient justification for the additional expense.

*Cost of power for operation.* The total cost of the power necessary for operating these plants is not vastly different for the two types, except in special cases in which the larger pumping cost for the intermittent plant may amount to a considerable item of expense.

*Cost of labor.* In very large plants, say, 50,000 gallons per hour or more, the amount of labor required for the two types of plants is approximately the same, since in both cases the entire time of one man is usually devoted to the care and operation of the plant. In smaller plants, however, there is a marked difference in the amount of labor required. For plants ranging from those of very small size up to about 20,000 gallons per hour, the total time required in the case of the continuous softener should not exceed about 3 hours; while in the case of the intermittent plant, practically the entire time of one man will be required.

This difference in the amount of labor involved is due, of course, to the fact that in the case of the continuous softener the chemical feeding tanks may be filled very quickly with enough of the reagents to treat water for a good many hours' supply; or in the case of the intermittent softener the succession of filling, treating, and emptying operation is necessarily so frequent that a man's time is pretty well occupied.

*Comparison of results obtained*

Assuming proper operation in both cases, properly treated water can be obtained from either type of apparatus. The particular

field of usefulness of the intermittent type of softener has been held to be for waters of variable composition, such as those of rivers and of other sources of supply. The validity of this statement is not evident upon a careful examination of the method of operation of a typical intermittent softener, nor of the results obtained. The ideal way to handle water in an intermittent softener, of course, is to take a sample of the water shortly after it has been thoroughly mixed with chemicals, and from tests on this water determine what change, if any, is necessary in the treatment. If a change is found necessary, which could easily be the case with a water of changing composition, the tank of water would have to be held until the treatment was adjusted either by the addition and agitation of more chemicals, or by the waste of treated water to allow for dilution with enough raw water to compensate for the overtreatment. The loss of time involved here would so lessen the effective period of service of a tank that the number of tanks would have to be increased to provide for such contingencies. Observation of the actual operation of intermittent plants shows that as rule the charge of one tank is based upon the chemical test made on the water of the previously treated tank; that is, the treatment of any particular tank is at least one tank behind any change in composition of the water.

In general, the human element would seem to play a greater part in the operation of an intermittent softener than in a continuous plant, since the number of man-made operations is considerably greater during the course of a day's operation.

### STUDY B. ECONOMIC VALUE OF LIME-SODA SOFTENING PRELIMINARY TO ZEOLITE SOFTENERS

The economic value of lime-soda softening preliminary to zeolite softening is dependent upon so many conditions that perhaps the best that any committee can do for the guidance of the general public in this respect is to point out the conditions which will affect the economic value of preliminary treatment so that these points will be given consideration when this question is decided.

Such preliminary treatment as the water requires for filtration purposes may be disregarded, for it is assumed that it is well understood that all waters containing suspended matter must be satisfactorily filtered before delivery to a zeolite softener. Whether or not sedimentation must be provided ahead of the filters is purely

a filtration problem. The water must be made crystal clear before delivery to a zeolite softener.

Consideration must be given to the following:

1. *Direct use to which softened water will be applied.* If the softened water is to be delivered to evaporators the presence of a large amount of sodium carbonate will not necessarily be seriously objectionable. Likewise, the sodium carbonate is not objectionable if required to soften the make-up water of the circulating system when using a cooling pond, to prevent scale formation on the tubes of surface condensers.

Where zeolite-softened water is fed directly to the boilers the high sodium carbonate resulting from this treatment is objectionable for the following reasons:

*a.* There is a tendency to cause foaming and priming of boilers because of high alkalinity concentrations in the boiler. To prevent priming the boilers must be blown down sufficiently, the amount of water depending upon the type of boilers, the rate at which boilers are fired, and other operating conditions.

The question in this respect that must be considered is "How much less will the boilers need to be blown down to prevent priming if the water is given preliminary softening before zeolite softening than if the zeolite softener is used alone?" Clearly the blow-down losses for boilers operated at high ratings will exceed the losses for comparatively small boiler plants where customarily boilers are not much overloaded. For small boiler plants unquestionably zeolite softeners have been used with satisfaction without pretreatment, whereas for larger plants with boilers operated at considerable overload pretreatment would be necessary before zeolite softening.

*b.* The probable effect of the sodium carbonate on caustic embrittlement of boiler plate is not well understood. The May, 1925, issue of *Mechanical Engineering* gave the suggested rules for care of power boilers which contained the recommendation that for working pressures of 150 pounds and under the alkalinity in terms of sodium carbonate should not exceed the sodium sulphate; for working pressures over 150 pounds and under 250 pounds alkalinity not to exceed one-half the sodium sulphate; for working pressures of 250 pounds and higher, alkalinity not to exceed one-third the sodium sulphate.

Many water treated by zeolite softeners will give a ratio of sodium carbonate to sodium sulphate unfavorable to the above recommendations of the A. S. M. E. Boiler Code Committee. To de-

termine the economic value of pretreatment from the standpoint of embrittlement it is not only sufficient to give consideration to the amount of temporary hardness in the raw water, but the amount of sulphates present must also receive consideration. This will, furthermore, obviously be dependent upon the boiler pressure. The higher the boiler pressure the more necessary the pretreatment for a given water supply.

The after-treatment of a zeolite-softened water with sulphuric and phosphoric acid is now being done in a number of commercial plants to lower its alkalinity.

*2. Cost of pretreatment.* The cost for additional equipment for pretreatment is considerably greater per thousand gallons of water treated for small capacities than large. Consequently, it would follow that pretreatment might prove economical for comparatively large installations, whereas it might not be economical for small capacities. The comparative costs must therefore be considered.

Again, it is obvious that the additional cost of equipment for pretreatment to lower the carbonate hardness will be considerably less if in any event the water requires filtration. Particularly is this true if the water requires sedimentation ahead of the filters. If before delivering water to the zeolite softener the water must be filtered and also settled, the additional cost for pretreatment of the water for lowering the hardness will be much less than if a city supply of well water, that does not require filtration, were available.

The cost of chemicals for removal of the temporary hardness is ordinarily less than the cost of salt, considering that for calcium carbonate hardness more than 4 pounds of salt must be used for the equivalent accomplished by 1 pound of hydrated lime, for precipitation of magnesium carbonate 2 pounds of salt are required for the equivalent of 1 pound of hydrated lime. The costs of salt and lime vary quite considerably depending upon the proximity to the source of salt and hydrated lime. Freight rates have an important bearing on these costs.

Comparative cost of pretreatment must also be considered with an after-treatment of a zeolite-softened water with sulphuric and phosphoric acid which is now being done in a number of commercial plants to lower the alkalinity of zeolite-softened water.

This question must also be considered in comparison with the cost of equipment for softening the water without introducing large amounts of sodium carbonate as may be obtained by hot process and cold-process lime and soda softeners.

From a study of the above it is evident that the question of whether or not pretreatment is advisable becomes complicated if an attempt is made to derive a formula applicable to all conditions whereas a consideration of all the above factors generally becomes very simple for any plant if all the conditions are known. It is therefore believed that the best that this Committee can do is to point out the influencing factors, the most important of which have been mentioned above.

### STUDY C. ECONOMIC VALUE OF LIME-SODA SOFTENING PRELIMINARY TO EVAPORATORS

The economic value of lime-soda softening preliminary to evaporators is dependent upon so many conditions that a number of the recommendations made for pretreatment to zeolite softeners in our previous report will be applicable to pretreatment for evaporators.

A survey of the central stations using evaporators indicates that waters containing 10 grains or more "total hardness" are being given pretreatment, and that waters containing 6 and 7 grains total hardness are being evaporated without apparently giving serious trouble.

A total of 55 questionnaires was sent out to central stations throughout the country, using evaporators, requesting data relative to operating conditions, cleaning, nature of water, etc. The results of this survey are classified as follows:

Class 1. Eighteen questionnaires have not been acknowledged (32.7 per cent). A second attempt was made to obtain data from these companies, but apparently without success. The possible explanation for this may be that questionnaires were addressed to holding companies as well as to the individual company.

Class 2. Thirteen users acknowledged the questionnaire, but for various reasons have not furnished information (23.6 per cent). These were returned not filled out for various reasons: equipment not yet in service; equipment in stand-by plants; equipment not been in service long enough to accumulate data; no available data, etc.

Class 3. Twenty-four users returned the questionnaire filled out as requested (43.7 per cent). These questionnaires containing the requested data have been carefully analyzed, and from this information our report has been prepared.

The analysis of the questionnaires indicates that 42 per cent of the users regard pretreatment warranted on account of scale, but 58 per cent of the users regard pretreatment not warranted. Of the 42 per

cent who regard pretreatment warranted, 21 per cent use external softeners, 12.6 per cent use internal treatment, but do not regard it satisfactory, and 8.4 per cent give no treatment, but recommend it.

A careful examination of the chemical analysis of the waters used by the above installations indicates that with the exception of one water all have a "total hardness" of 10 grains or higher. The one exception has a "total hardness" of only 6 grains. Of the 58 per cent who regard pretreatment *not* warranted, 53.9 per cent use water less than 6 grains "total hardness," and 4.1 per cent use water of 7 grains "total hardness."

One installation of the above 58 per cent treats the water with sulphuric acid to give a more favorable relation of sodium sulphate to sodium carbonate on account of water naturally containing 6 grains of sodium carbonate per gallon. This is done because the evaporator gives off some moisture, and soluble salts are formed in the distillate.

It would be a difficult matter to try to indicate the average saving in dollars and cents to be obtained by pretreatment ahead of evaporators as there are so many variables to be considered, i.e., the amount of water evaporated between cleanings; the condition of the water; irregular cleaning periods ranging from one week to one year; reduction in capacity varying from 2 to 50 per cent, and cost of cleaning varying from $20 to $600.

The cost of additional equipment for pretreatment might be considerably greater per thousand gallons of water treated for small capacities than for large capacities; consequently it would follow that pretreatment would prove economical for comparatively large installations, whereas it would not be economical for small capacities.

The most significant facts brought out by this investigation are that waters containing 10 grains or more "total hardness" are being given pretreatment, and that waters containing 6 and 7 grains "total hardness" are being evaporated without apparently giving serious trouble.

In conclusion, we wish to thank the central stations for the generous manner in which they furnished us with the information requested.

# PRESENT KNOWLEDGE OF FOAMING AND PRIMING OF BOILER WATER, WITH SUGGESTIONS FOR RESEARCH

## Progress Report of Sub-Committee No. 3 on Zeolite Softeners, Internal Treatment, Priming and Foaming, and Electrolytic Scale Prevention[1]

By C. W. Foulk, *Chairman*

In 1893 Stromeyer[2] in his work on marine boilers wrote that information on the subject of priming was "almost non-existent." Eighteen years later Stabler[3] evidently felt that little information had been added, for he began his section on foaming and priming with the statement that they "are probably the least understood of boiler phenomena." At the present day, sixteen years later, Stabler's statement still holds. The only modification that suggests itself would be to leave out the word "probably."

[1] The personnel of Sub-Committee No. 3 on Zeolite Softeners, Internal Treatment, Priming and Foaming, and Electrolytic Scale Prevention, of the Joint Research Committee on Boiler-Feedwater Studies is as follows:

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[2] C. E. Stromeyer, Marine Boilers, p. 42 (1893).

[3] Herman Stabler, Eng. News, vol. 60 (1908), p. 355 and U. S. Geological Survey, Water Supply Paper 274, p. 171 (1911).

## PHENOMENA TO WHICH THE NAMES "FOAMING" AND "PRIMING" HAVE BEEN APPLIED

Much effort has been expended in the past in trying to define "priming" and "foaming." A search of the literature shows utter confusion in the use of these terms. Some authors employ them interchangeably. Some call a foam on the surface "priming," and others call violent ebullition "foaming." Indeed, it can be said that a reader of any book or paper will not know what is meant unless the writer defines his terms.

Fortunately the question can be approached another way. Instead of seeking the meaning of the terms one can differentiate and describe the phenomena to which these various names have been applied. From this standpoint, then, an examination of boiler-water papers shows that one or more of three fairly distinct mental pictures of phenomena inside the boiler were in the minds of writers when they used the terms "foaming" and "priming:"

1. The formation of foam on the surface of the water. This foam may range in thickness from a layer barely covering the surface to a mass that fills the steam space above the water. In the latter case the liquid films around the bubbles would be drawn into the steam pipe and wet steam would result.

2. Another phenomenon evidently in the minds of certain writers is merely rapid ebullition with the consequent projection of droplets or even slugs of water into the steam pipe. This could happen without the appearance of foam as it is described above.

3. A third situation partakes both of the properties and appearance of foam and of violent ebullition. The boiling is of such a character that the whole mass of water from the bottom up is full of fine steam bubbles, with the consequence that the interior of the boiler is filled and of course much water passes out with the steam.

It should be emphasized, perhaps, that the three situations pictured above are not necessarily descriptions based upon actual observations of steam boilers in operation. If such observations have been made the author has failed to find the record of them. They are to be looked upon more as reasonable suppositions by men of experience with steam boilers, and who have undoubtedly observed analogous situations in glass flasks or open metal vessels. Moreover, some writers evidently have no picture in mind of what goes on inside the boiler. They simply use the terms as meaning any entrainment of water by the steam.

Systematic research may show that a fourth phenomenon, namely, the manner in which bubbles break on the surface of the water in the boiler, should also be considered, at least as one of the causes of wet steam. This idea was first suggested to the author by Dr. R. E. Hall, who used the phrase "smoothness of boiling."

It is well known that a bubble breaking on the surface of a liquid projects a droplet of the liquid to a height of several inches. This phenomenon has never been studied so that nothing is known of its mechanism or of any way of controlling it. It seems reasonable to suppose that a continual projection of droplets of water into the steam space would be a large factor—perhaps the determining factor—in causing wet steam when other conditions were normal, that is, when there was no foaming or priming.

The confusion of terms that exists is deplorable, and now that an official committee[4] representing a number of interested engineering societies is at work on this feature of boiler-water behavior, one of its first duties should be the clarification of the nomenclature. However, before permanent definitions are formulated there should be an extensive series of accurate observations made, if possible, on actual steam boilers, and failing that, on experimental boilers, in order to determine with some precision the various causes for the entry of water from the boiler into the steam. Appropriate names can then be found for the phenomena.

## CAUSES OF FOAMING AND PRIMING

*Physical.* The causes of foaming and priming as given in boiler-water papers fall under two general heads, physical and chemical. Among the physical causes the design and operation of the boiler are outstanding. The more complex the interior—that is, the more of a maze of tubes, staybolts, etc., there is in the boiler—the more likely is it to foam (prime). It is also evident that, other conditions being the same, the smaller the steam space above the water, the more likely is water to be carried out. If the boiler is moved about rapidly while in use, as is the case with railroad and marine boilers, the extra agitation will promote foaming.

Violent ebullition for a few seconds may result from the sudden evolution of steam following a period of superheating of the water analogous to the familiar "bumping" of liquids in the laboratory.

[4] Jour. Amer. Water Works Assoc., vol. 13 (1925), p. 336.

A similar effect would be produced by the loosening of a sheet of scale, which would thus bring water into contact with almost red-hot metal. The sudden introduction of solid matter, entering with the feedwater or produced by the loosening of scale, also causes a violent ebullition for a few seconds, and a rapid opening of the steam valve by causing a momentary lowering of the pressure has the same effect.

There is some difference of opinion as to the relation of steam pressure to foaming, but the majority seem to hold that high-pressure boilers foam less than low-pressure ones. Such a statement seems logical because a given weight of steam occupies less space the higher the pressure it is under.

*Chemical.* The available information about the chemical causes of foaming may be classified inder (1) substances that cause foaming, and (2) physico-chemical explanations of the phenomenon. The offending substances are listed under such indefinite terms as "organic matter," "impurities," "oily matter," "soap and soapy substances," "saline matter, " "alkalis," and "suspended solids." Sodium salts seem to be the only definite chemical substances to which foaming and priming are generally attributed, but the author has not been able to find a record of any experiments which show that sodium salts alone are the cause of the trouble. The belief has unquestionably originated from the fact that in the great majority of waters sodium salts are the only ones that concentrate in the boiler. Others that are present in any quantity, such as calcium and magnesium compounds, precipitate for the most part.

Next to sodium salts finely divided solid matter is held responsible for foaming and priming, and some go so far as to assert that solids are the only cause, barring, of course, occasional cases of soap or peculiar forms of organic matter in the water. Here again, however, the record of experimental evidence in favor of this view is lacking.

In 1924 the author[5] acting on a hint from Bancroft[6] succeeded in harmonizing the conflicting statements concerning the effect of sodium salts and solid matter. An extensive series of laboratory experiments showed that sodium salts alone or finely divided solids alone did not cause a true foam, but that when both were in the

[5] C. W. Foulk, Ind. & Eng. Chem., vol 16 (1924), p. 1121.

[6] Applied Colloid Chemistry, General Theory, p. 268. McGraw-Hill Book Co., N. Y. (1921).

water in sufficient concentration foaming resulted; that is, a true foam or froth several inches thick was produced on the surface of the water. The explanation of this is given below.

### THE PHYSICO-CHEMICAL THEORY OF FOAMING

Wherever the word "foam" or one of its derivatives is used in this section, it refers to a true froth or foam as described in No. 1 above.

It must be said at the start that there is as yet no comprehensive physico-chemical theory of foams. This fact, perhaps more than any other, retards the progress of research in this field. The statement frequently found that foaming is caused by lowering the surface tension of a liquid seems merely to express a coincidence. While it is true that the foamiest liquids (for example, soap and saponin solutions) have low surface tensions, it is also true that pronounced foaming can be produced by conditions that raise the surface tension. Water solutions of inorganic substances—sodium salts, for example—foam readily if the films are estabilized by finely divided solid matter. (See below.)

Furthermore there is no quantitative relation between the lowering or raising of the surface tension of a liquid and the foam producing power of the resulting solution. Water solutions of soap and saponin, for instance, may be equally foamy, the saponin even foamier than the soap, and yet the surface tension of the saponin solution will be much higher than that of the soap.

This question of the lack of relation between surface tension and foaming is discussed at length by Wo. Ostwald and A. Steiner,[7] who give many literature citations. The immediate relation of the problem to boiler water is touched upon by Millard and Mattson,[8] who show that what they call "priming" is in no way related to surface tension. Though these investigators do not distinguish between true foam and other phenomena, the description of some of their experiments leads one to think that foam should have been present.

About all that can be said is that pure liquids do not foam.[9] Something must be present of such a nature that its concentration in the surface differs from that in the mass of the liquid. This interesting

[7] Kolloid-Zeitschrift, vol. 36 (1925), p. 342.

[8] E. B. Millard and T. E. Mattson, Ind. & Eng. Chem., vol. 17 (1925), p. 685.

[9] Freundlich, Kappillarchemie, 2nd Ed., p. 1091 (1922).

situation is quite common and can be shown by laboratory experiments. If, for example, a mass of soap bubbles is collapsed the resulting liquid will be found to contain more soap per unit volume than did the original solution from which the bubbles were produced. Whether there is more or less of the added substance in the surface than in the interior of the liquid seems to make no difference. Either way, the surface layer differs from the rest of the liquid and thus makes possible a separation of films from the surface. This separation of films is the necessary condition for the formation of foams. There is, however, another condition which, if not theoretically necessary is practically so, namely, the stabilization of the films. Most bubbles burst in the moment of their formation and therefore cannot form a foam. The films of a true foam must have a certain structural strength and period of existence. This is given by the viscosity of the film itself, as in the case of soap bubbles, or by the addition of finely divided solid matter which imparts the necessary viscosity, as in the case of the foams of sodium salt solutions stabilized by pulverized boiler scale. (See below.)

No one has yet offered a plausible explanation of why a pure liquid does not foam and why a difference in concentration between surface and interior of a solution permits the separation of films. When a bubble generated in the interior of certain solutions rises to the surface it lifts a film; or when a ring composed of any solid that is wet by the liquid is applied with appropriate technique to the surface and lifted, a film is removed. What now determines the plane of separation of that film from the remainder of the liquid? The answer to that question would be the general theory of foaming.

The author believes that research on this fundamental problem should be directed to a study of the conditions which control the maximum *thickness* of films. Heretofore attention has been focused on their minimum *thinness*. Bancroft[10] who is an omnivorous reader, says, "I have not been able to find any statement as to the maximum thickness of a soap-bubble film; but it is certainly not less than $1.4\mu$." This is many hundred times as thick as the layers of oriented molecules pictured to account for surface-tension phenomena. In general, it would be well to direct research to the relatively thick ($1.0 \pm$ mm.) layer at the surface of liquids. It is the seat of peculiar phenomena. Liebreich called it the "dead space in

[10] Applied Colloid Chemistry. General Theory, Second Edition, p. 456. McGraw-Hill Book Co., N. Y. (1926).

chemical reactions" because certain reactions at least fail to take place in it. Hannan[11] refers to another phenomenon peculiar to this region, namely, the very rapid rate of sedimentation in it.

The relation of surface concentration to surface tension is in the sense that those substances which concentrate in the surface lower the surface tension, and those which recede from the surface increase the surface tension. It can also be shown both theoretically and practically that surface tension can be lowered to a much greater extent than it can be raised.

In general, organic substances lower the surface tension and inorganic ones raise it. There are, however, exceptions to this rule. Cane sugar, for example, slightly increases the surface tension of water and hydrochloric acid slightly lowers it.

### APPLICATION OF THEORY TO BOILER WATER

On applying these principles to boiler water, it can be said that the fundamental condition of foaming is the presence of substances which concentrate either in the surface or in the mass of the water. If, however, these substances do not at the same time have the property of making the films around the bubbles stable, there will be no foam in a practical sense, because the life of the bubbles will be too short—they will burst a moment after forming. It is necessary, then, to distinguish carefully between the two conditions for the formation of foam—(1) the presence of something which, by modifying the surface of the water, makes possible the formation of bubbles, and (2) the presence of something which by imparting viscosity to the films will stabilize them—that is, prevent them from bursting immediately after forming. This necessary viscosity can, of course, be produced by the same substance which changes the surface. Soap, for example, is such a substance, and an occasional water is found in which the organic matter present has this property, either as it enters the boiler or after modification by the action of the superheated water. In the average boiler water, however, the change in the surface is brought about by dissolved sodium salts and the stabilization of the foam by finely divided solid matter. The presence of either one without the other is not sufficient to cause foaming.

[11] Frank Hannan, Jour. Amer. Water Works Assoc., vol. 10 (1923), p. 1035.

The action of the particles of solid in stabilizing the foam appears to be purely mechanical. Edser,[12] in a paper on ore flotation, pictures the situation as follows:

> Imagine a number of bubbles in the interior of a liquid, each bubble being coated with mineral particles. When these coated bubbles come into contact after rising through the liquid, the walls of each cell will consist of numerous solid particles held together by films of liquid.

In flotation the solid particles are frequently the only stabilizing agent present. It must, of course, be emphasized that to stabilize a boiler-water foam as well as that of a flotation process the solids must have the property of adhering to (being adsorbed on) the films. Flotation as a method of separation would be impossible if solids did not behave differently in this respect and, it might be added, boiler foaming would be a rare occurrence were it not for the unfortunate circumstance that the solids usually present in a boiler have the property of adhering to the films around the steam bubbles.

Whether there is a manifest difference in the stabilizing effects of the different types of boiler scale has not yet been determined. Work now in progress in the author's laboratory suggests at least that this point should be investigated.

Other things being equal, the stabilizing effect increases as the size of the solid particles decreases. It is interesting, however, to note that particles so large that none will pass through a forty-mesh sieve can be seen adhering to the steam bubbles.

Koyl[13] gives the presence of finely divided solids as the cause of the phenomenon described above under (3), but merely states that each particle becomes a nucleus from which a stream of steam bubbles rises. It would not be too far-fetched to assume that the particles that act in this way have entrained minute bubbles of air, or perhaps of carbon dioxide, which would then serve as permanent gas-phase surfaces at which steam bubbles would form. The stabilizing effect of the finely divided solid matter would tend to hold such steam bubbles intact—that is, prevent them from coalescing. In this way

[12] Edwin Edser. Fourth Report on Colloid Chemistry, and Its General and Industrial Applications, British Association for the Advancement of Science, p. 263.

[13] Railroad Gazette, vol. 32 (1900), p. 663.

the mass of the water would become filled with bubbles, as Koyl describes.

In the author's previously mentioned paper a large number of laboratory experiments in glass flasks are described. This experimental evidence is too long to reproduce here, but is referred to because it furnished the confirmation of the theories advanced and which are given above. There is also another reason for referring to it. Ordinarily, laboratory experiments offer an unsafe guide for large-scale industrial operations, so that it is worth while in this case to record that the author has received additional evidence in the shape of a number of letters from persons of practical experience with steam boilers. These letters uniformly uphold the general conclusions of the paper, so that, in a way at least, it can be said that these laboratory experiments have been confirmed in practice.

## ORGANIC MATTER AS A CAUSE OF FOAMING

Practically nothing is recorded concerning causes of foaming other than those mentioned above. The author has received two private communications to the effect that excelsior used as a filter in a water softener caused foaming during the first few days it was in use, after which the effect disappeared. This would mean of course that the water dissolved out certain organic materials that caused the trouble. Another communication cited the organic matter in certain of the highly colored surface waters of Florida as a cause of foaming. It would be interesting to know whether such colored waters from other parts of the country have the same effect, for example, those from New England. The question of the behavior of these waters, if at the same time they contain sodium salts and finely divided solids, is one that has not yet been studied.

## TESTING WATER TO DETERMINE WHETHER IT WILL FOAM

A practical question naturally arises, namely, what chemical or physical tests can be made on a boiler water in order to determine whether it will foam? This point has never been thoroughly studied. Boiler-water chemists would determine the sodium-salt concentration and base their conclusions on the result. Stabler (footnote 3) in his famous paper giving equations by which the behavior of a water can be calculated, includes one on foaming which gives what he calls the "foaming coefficient." It is nothing more than an approximate value for the sodium and potassium salts in the water, and obviously

would not apply unless finely divided solids were also present. If sodium salts and suspended solids were both measured a very good guess could be made as to the foaming susceptibility of the water. Unfortunately, however, it would not be safe to reason in the converse way, because some waters that are very low in sodium salts and suspended solids nevertheless will foam.

A foam test is still to be devised. Some preliminary work in the author's laboratory suggests the possibility of developing something practical from so simple an operation as blowing air into the water to be tested. If the air enters in very fine bubbles, as when blown through a porous septum, a foam seems to be produced, even at room temperature, in all waters that foam on boiling, and vice versa. There is also the "membrane meter" of Wo. Ostwald and Steiner (footnote 7). These investigators found that when the level of a liquid in a capillary tube is raised or lowered the rate at which the liquid surface returns to its original position is inversely proportional to the foaming susceptibility of the liquid. The original paper must be consulted for the details of the experiment.

In applying these or any other test to a boiler water, however, one must not forget that the raw water and the same water after it has been subjected to the high temperature of the interior of a modern steam boiler are by no means the same things. Nevertheless the development of a foam test is worth some research.

## PRIMING

"Priming" as used in this section has a special meaning, namely, the projection of water into the steam space due merely to violent ebullition. In most cases, perhaps, it results from the ebullition of spasmodic violence accompanying the breakdown of a condition of superheating. Unpublished work done in the author's laboratory shows that in glass flasks at least it is far easier than has been supposed to heat water above its normal boiling point for the pressure of the moment. Indeed, the water may be boiling, that is, copious bubbles of steam may be rising through it, and yet its temperature will be one or two degrees fahrenheit above the normal boiling point. If now, with the water in this condition, it is subjected to a shock of some sort, like the introduction of a little solid matter or the addition of a slug of water from the outside, the superheated state breaks down and the stored-up energy is dissipated by a few moments of violent ebullition, the temperature of course falling to the normal.

Every one of course knows these facts about the superheating of liquids, but it is doubtful if many know how common the phenomenon is.

Other experiments were of the following nature. Flasks were so equipped that the steam from the boiling water in them escaped through a small orifice and therefore some inside pressure could be maintained and at the same time have the boiling proceed. If now a large valve in the stopper were opened the pressure of course dropped, the water was left at a temperature a degree or so above its normal boiling point for the lower pressure and consequently there was violent ebullition for a few seconds, so violent that large slugs of water were projected into the steam space.

If a similar situation can occur in a boiler when the steam valve is rapidly opened, the violent ebullition that will follow for a few seconds may easily throw slugs of water into the steam line. The important point to note in these experiments is that this "priming," as it is called, can take place with pure water. It is independent of the conditions of film formation, etc., that are necessary for "foaming," in other words, it is a separate phenomenon and therefore merits study as such.

The question naturally arises, what happens when the flasks are charged with sodium-salt solutions alone, suspended solids alone, or with both sodium salts and suspended solid matter? The answer is, that dissolved matter alone or suspended matter alone increases the "priming" only slightly, but when both dissolved and suspended matter are present the priming is many fold that of pure water. The effect described in No. 3 above can be observed at times, that is, the water lifts by becoming a mass of steam bubbles. Owing to the fact that "priming" is so greatly increased in a water in which the conditions for the formation of stabilized films also exist, it is difficult to distinguish between "priming" and "foaming." In the situation just described it would be logical to say that the "foaming" was greatly increased during a few seconds by the "priming."

## THE PROJECTION OF DROPLETS OF LIQUID BY BURSTING BUBBLES

So far as the author is aware, no studies have ever been made of the nature of evaporation from the standpoint of the projection of droplets of liquid into the steam space by the bursting of bubbles. Perhaps very slight additions of the right substances to a boiler water would cause its boiling to proceed with such "smoothness" that little or no water would be thrown up. The idea is fanciful, but nevertheless is worth at least a little laboratory experimentation.

### REMEDIES FOR FOAMING AND PRIMING

The two outstanding methods of reducing foaming and priming are (1) reduction of the concentration of sodium salts, suspended solids, or other offending substances by blowing down the boiler, and (2) the introduction of castor oil into the boiler water. The first remedy is efficacious in about the extent to which the concentration of the offending substances in the water is reduced. Such a relation is so obvious that no theoretical discussion is needed. It is equally obvious that there is a heavy loss of energy in wasting water that has been heated to the temperature of the boiler, and therefore blowing down has severe limitations. Finally, the plan has no effect when the foam producing impurity is in the raw water.

Remedy No. 2, the use of castor oil, is perhaps the most interesting and effective treatment applied to industrial water. Its effect on the stabilized foams resulting from dissolved salts and suspended solids is like a touch of magic. A mere trace of this oil, less than 0.001 per cent by volume, causes the instant disappearance of the type of foam referred to above.

In actual practice castor oil is seldom or never used as such because it is not miscible with water and therefore difficult to apply in a uniform way. The general procedure is to prepare an antifoam compound by emulsifying the oil with starch and other ingredients to give a mixture containing 14 to 15 per cent of oil. This will mix uniformly with a large quantity of even cold water so that the introduction of any desired amount into the boiler is easy.

On one of the Ohio railroads the rule[14] is not to begin using antifoam till the boilers begin to foam, which usually takes place when the concentration of dissolved solids reaches 3000 parts per million (175 grains per gallon). A pint of anti-foam compound, containing 16 per cent of castor oil, is then put into the tender tank, which holds 5000 gallons of water. This would mean a concentration of less than 4 parts per million (about 0.2 grain per gallon) of actual oil in the water, and yet by its use the boiler can be kept going till the concentration of dissolved solids reaches double the value given above.

This effect of castor oil in inhibiting foam is apparently confined to that type of foam in which the films are stabilized by suspended solid matter. "Apparently" is used advisedly because the matter has never been systematically studied. A few experiments in the

[14] Personal communication from C. P. Hoover.

author's laboratory seemed to show, for example, that the oil had no effect on a soap foam.

A few other oils also inhibit foam as castor oil does, but for one reason or another have never come into use. Bardwell[15] found that pine-tar oil worked satisfactorily up to 140 lb. pressure, but not beyond. Incidentally, it might be remarked here that during the World War many experiments were probably made in search for substitutes for castor oil as an anti-foam. If this is true they ought to be recorded somewhere.

There is little or nothing on record concerning the prevention of foaming due to dissolved vegetable matter. French[16] found that alum served to prevent the foaming caused by dissolved vegetable matter in a highly colored Florida surface water. This is interesting because the generalization is perhaps warranted that such foam-producing substances can be rendered harmless by adsorbing them on precipitated aluminum hydroxide.

When the question of a physico-chemical theory of the destruction of foam by castor oil is raised, the answer must be, there is no theory. One may guess that the action is due to the destruction in some way of the stabilizing action of the suspended solids rather than to any effect on the liquid films. Perhaps the best way to get suggestions on this point is to study the data of ore flotation. Edser's paper (footnote 12) in this connection is admirable.

## FOAMING AND PRIMING AS A RESEARCH PROBLEM

Since the underlying purpose of this paper was to suggest points of attack in research work on the problem of foaming and priming of boiler water, it will be worth while now to classify the suggestions offered above. They fall naturally into two groups.

I. Research with the object of finding the fundamental causes of foams and stabilized films in such water solutions as may occur in a steam boiler. This is a laboratory problem calling for measurements of surface tension, surface concentration, and viscosity, thickness of liquid films, angles of contact between solids and liquids, and long, patient experimentation with one combination of materials after another. Coincident with the above will be a line of experimentation with autoclaves or small experimental boilers.

[15] R. C. Bardwell. Personal communication to the author.

[16] D. K. French. Personal communication to the author.

This is the kind of work that is adapted to university surroundings in which the necessary scientific instruments, books, and journals are to be found.

II. Research involving experiments with actual steam boilers under working conditions. This is preëminently the point at which the practical man comes in, and it is fortunate that the organization of the committees having this work in charge (footnote 4) includes practical as well as theoretical men. The prospects for coöperation are fine.

There is of course no reason why these two groups of research should not mix in any proportion that circumstances may bring about, and it is certainly the wish of the author of this paper that they should be so mixed.

# EMBRITTLEMENT OF STEEL

## Progress Report of Sub-Committee No. 6 on Embrittlement of Metals[1]

By Alexander G. Christie, *Chairman*

The work of this Committee has been confined to the consideration of the embrittlement of steels used in steam boilers. This subject has been receiving much study both here and abroad and many conflicting views have been submitted to the committee for consideration. These have been carefully considered and analyzed.

There are two schools of thought in regard to this subject. Certain engineers, after studying embrittlement from many angles, have been led to the conclusion that such embrittlement as occurs is promoted by the presence of caustic in the waters in the boiler resulting from the occurrence of sodium carbonate in the feed-water. Other engineers, also after careful study of the phenomena, have concluded that other causes contribute to this type of failure and that the presence of caustic is not the controlling factor.

[1] The personnel of Sub-Committee No. 6, on Embrittlement of Metals of the Joint Research Committee on Boiler Feedwater Studies is as follows:

Alexander G. Christie, *Chairman,* Professor of Mechanical Engineering, Johns Hopkins University, Baltimore, Md.

Henrich Kriegheim, Technical Manager, The Permutit Company, 440 Fourth Avenue, New York, N. Y.

A. S. Behrman, International Filter Company, 333 West 25th Place, Chicago, Ill.

John H. Buell, Manager of Operations, Oklahoma Power Company, Tulsa, Okla.

R. E. Coughlan, Chicago and Northwestern Railroad, Chicago, Ill.

D. K. French, Dearborn Chemical Company, 310 South Michigan Avenue, Chicago, Ill.

John Hunter, Mechanical Engineer, 805 Merchants-Laclede Building, St. Louis, Mo.

J. B. Romer, The Babcock and Wilcox Company, Bayonne, N. J.

Albert E. White, Professor, Director, Department of Engineering Research, University of Michigan, Ann Arbor, Mich.

R. S. Williams, Professor of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

This report will summarize the evidence and reasoning of both schools of thought and will attempt thereby to give engineers a definite idea of the problems involved. The Committee does not believe, in view of the data before it, that it is possible at the present time to reach any final conclusions regarding the cause and remedy of this trouble. Certain facts seem to be established and these will be presented. The Committee also makes certain recommendations at the close of its report.

The following outstanding facts are presented as indicating the present status of knowledge of the phenomena:

*a*. Embrittlement of boiler metal is an established fact and not a myth as believed by some engineers.

*b*. The difficulty has not been encountered in any one section of the country, although there are certain areas where failures of this kind have been more prevalent.

*c*. In most cases where these failures have been experienced, the water has contained relatively high concentrations of carbonate, bicarbonate or hydrates of soda and these waters have been low in sulphates or chlorides of soda. Some cases of embrittlement of boiler metal have occurred, however, with waters where the concentration of sodium salts was low.

*d*. Embrittlement is a function of excessive stresses in the metal, and the phenomenon apparently does not occur in the absence of stresses beyond the elastic limit for the metal.

*e*. It has been shown experimentally that embrittlement of boiler steel may be produced at will in the presence of excessive amounts of hot caustic soda (20,000 grains per gallon) when the metal is under tension beyond the elastic limit. The phenomenon takes place usually by the combined action of high stress and high chemical concentration. These facts have been established by laboratory experiments, but the element of time affecting the phenomenon has not been established.

*f*. Laboratory experiments and experience in practice indicate that the embrittlement of the metal may be inhibited by maintaining a specific ratio between the sodium carbonates and sulphates present in the water.

*g*. Failure of the metal progresses by intercrystalline fracture. In practically all cases there is no deformation of the grains.

*h*. One investigator has determined that a similar phenomenon may be produced by calcium nitrate.

Various investigators are by no means in accord concerning the basic cause or causes of the phenomenon, and much discussion has arisen as a result of the two schools of thought. There are certain points, however, upon which there seems to be general agreement. These are as follows:

*a.* Brittleness of boiler steel may occur in the presence of high concentration of caustic soda and result from straining the metal beyond the elastic limit.

*b.* Failures of this kind are intercrystalline in character.

*c.* The cracking of metal occurs in practically all cases along the line of the rivets and on the dry side of the plates.

Certain investigators believe that the brittleness of metal is affected by the absorption of cathodic hydrogen, and that the rapidity of the action is accelerated by stresses in the metal. This view has not received universal acceptance.

Still others hold that embrittlement is due to the presence of such impurities as iron sulphide at the grain boundaries, which are dissolved by the action of caustic soda or other chemicals.

Some engineers believe that embrittlement is due partly to certain inherent characteristics of the steel and partly to stresses from deformation and riveting in the process of manufacture augmented by the stress due to the working pressure in the boiler. Evidence has been submitted to confirm this view.

### A REVIEW OF INVESTIGATIONS AND OPINIONS ON EMBRITTLEMENT

As early as 1866[2] Graham made the interesting discovery that red-hot iron was penetrated by hydrogen and that a portion of the hydrogen was retained by the metal after it had cooled down. Caillet[3] and Johnson[4] arrived at a somewhat similar conclusion and demonstrated that hydrogen generated electrically was absorbed by iron at room temperatures. They showed further, however, that hydrogen in a gaseous form apparently had no effect upon the metal. In Johnson's work it was shown that soft iron became embrittled in contact with electrolytic hydrogen. It was further shown by Johnson that the treatment of the iron with acid, prior to contact with the gaseous hydrogen, greatly accelerated the rate of embrittlement of the metal.

[2] Proceedings of the Royal Society, vol. 17, p. 219, 1869.
[3] Comptes Rendus, vol. 80, p. 319, 1875.
[4] Proceedings of the Royal Society, vol. 23, p. 186, 1875.

It was reported by Thompson[5] that fairly high concentrations of solutions of soda at boiling temperatures had no appreciable effect on the properties of soft iron. It was also shown by the same investigator that soft iron was much more seriously affected by boiling water. Somewhat similar results were obtained by T. S. Fuller.[6] This investigator showed that the rate of absorption or penetration of hydrogen through a sample of electrolyzed iron was practically the same with 1 per cent caustic soda as when tap water was used. W. D. Andrews reported the results of experiments in the Transactions of the Faraday Society, 1914, stating that strips of steel kept in concentrated sodium hydroxide solution at 212 deg. Fahr. for a period of from one to seven weeks were seriously embrittled. Hydrogen was evolved as the result of the action of the caustic soda. Most widely quoted experimental studies on this subject are those of S. W. Parr,[7] published in the University of Illinois Bulletins in 1917 and by Parr and Straub in 1926. The conclusions reached by these investigators are as follows:

*a.* Embrittlement in boiler plate is caused by the combined action of stress and chemical attack. The stresses are inherent in the construction and in the operation of the boiler, while the chemical attack is caused by sodium hydroxide in the boiler water.

*b.* Certain methods of water treatment tend to convert some safe waters into the characteristic type of water which produces embrittlement.

*c.* The presence of sodium sulphate in the feedwater and undecomposed sodium carbonate in the boiler water tends to retard the embrittling effect of carbonate waters, and if these are present in proper proportions they will stop it entirely.

*d.* Methods for introducing sulphates in boiler waters have been worked out to the point of practical application.

R. S. Williams and V. O. Homerberg report in the Transactions of American Society for Steel Treating, April, 1924, the results of their experimental studies carried on at the Massachusetts Institute of Technology. The conclusions of these investigators are as follows:

[5] Journal of Society of Chemical Industry, 1894.

[6] Transactions of the American Electrochemical Society, 1919.

[7] University of Illinois Bulletin, January 1, 1917, no. 94, and June 22, 1926, no. 155. (*Note:* Engineers interested in embrittlement should study carefully the last bulletin (no. 155) of Parr and Straub.)

*a.* During the crystallization of steel, the impurities, to a considerable extent, are rejected to the grain boundaries.

*b.* The oxides and sulphides are two of the prime factors in caustic embrittlement.

*c.* The oxides are reduced under the influence of cathodic hydrogen.

*d.* The sulphides are removed due to the action of hot caustic soda solutions.

*e.* The removal of the sulphides produces a surface condition favorable to progressive corrosion.

*f.* Assuming that progressive corrosion starts with the removal of the sulphides, the corrosion will be greatly accelerated if the material is stressed. Furthermore, when the steel is under tension there is a tendency for the matrix to pull away from the inclusions at the grain boundaries and in this manner to produce small capillaries into which the corroding solution can penetrate.

*g.* In stressed areas containing oxides, the volume increase, due to the reaction with cathodic hydrogen, may produce stresses which, added to those initially present, may cause cracking.

*h.* It seems evident that hydrogen acts in three ways to produce embrittlement: first, the temporary brittleness caused by absorbed hydrogen (as in acid pickling), second, it acts to reduce oxides, and third, its effect due to the change in volume at the grain boundaries, resulting because of the production of water. This latter volume increase would create a stress which, added to those originally present, may cause cracking, especially at those points where these stresses are at a maximum.

The 1922 Report of the Prime Movers Committee, National Electric Light Association, on Treatment of Feed Water, in discussing this phenomenon, gives the general characteristics present in the embrittlement of boiler plate as follows:

*a.* Occurrences ordinarily limited to the joints of the boiler.

*b.* Occurrence only in parts of the boilers reached by the water. This is most noticeable in girth joints, as up to the place reached by the water (not necessarily the normal water line), cracking is found, and beyond that point the plate is unimpaired.

*c.* Occurrence in the various members of the joint; that is, in the rivets as well as the plates, in both plates of a lap joint, or in plates and straps of butt joints.

*d.* Occurrence in rolled plates, cast steel or cast iron, according to the construction of the boiler.

*e.* When a plate is cracked, the line of the crack on the surface of the plate in contact with the surface of another plate is longer than the line of the crack on the other surface of the same plate (i.e., embrittlement starts at the surfaces in contact).

*f.* Extreme irregularity of the cracks with sharp changes of direction; paralleling without any marked tendency to join; in other words, the exact position of a crack is not determined by the stress due to the boiler pressure, though the general area affected may be.

*g.* Brittleness of the material under shock and fatigue, with very little indication of brittleness under static tests, and marked localization of the embrittlement to the joint area.

*h.* Loss of embrittlement (not necessarily total) with time when the boiler is removed from service, coupled with a marked degree of removal of embrittlement by heating at temperatures far below those required for ordinary annealing.

*i.* A plentiful deposit of a black, powdery substance on the affected surface which on analysis is principally an iron oxide.

Since the location of cracking of this sort is selective with respect to the parts of the seams reached by the water of the boiler, reference should be made to the feed conditions and apparently with the following conditions in mind:

*a.* Solubility will be of prime importance for the reason that a highly soluble substance may be present in heavy concentration without depositing anything on the metal to mechanically protect it.

*b.* These substances should not attack the metal in the concentration in which they usually occur in a boiler, but should attack the metal in the higher concentration that can build up in restricted areas like the boiler joints.

*c.* Acids can be eliminated from consideration, as they attack the entire metal surface at any concentration that could occur in boiler practice.

*d.* Substances of high specific conductivity would increase the corrosive effects resulting from potential differences in the boiler structure.

*e.* Substances such as calcium and magnesium carbonates, calcium sulphate, etc., being incrusting salts and of low specific conductivity, may be eliminated from consideration for either reason alone.

The soluble salts generally found in practice are given in table 1, column "A" showing solubility in grams per 100 cc. of water at 100°C.,

column "B" showing equivalent conductivity at 18°C. From this table, sodium hydroxide has the greatest index of solubility and conductivity. Sodium chloride is relatively low in both solubility and conductivity, and by itself is not known to be corrosive under boiler temperatures at any concentration. Magnesium chloride and calcium chloride, while higher than sodium chloride in solubility and conductivity, have hydroxides that are very low in solubility, and corrosion from these substances occurs even at low concentration on all exposed surfaces. Hydrolysis of sodium carbonate is very considerable under boiler temperature, and within the range of usual boiler concentration in its effect it may be regarded as though it were sodium hydroxide. Sodium sulphate will ordinarily occur in boilers as the

TABLE 1

| | "A" Solubility | "B" Conductivity |
|---|---|---|
| Sodium chloride | 39.12 | 92.0 |
| Magnesium chloride | 73.0 | 98.1 ($\frac{1}{2}$ $MgCl_2$) |
| Calcium chloride | 159.0 | 88.2 ($\frac{1}{2}$ $CaCl_2$) |
| Sodium sulphate | 42.5 | 78.4 |
| Magnesium sulphate | 73.8 | 76.1 ($\frac{1}{2}$ $MgS_4$) |
| Sodium carbonate | 45.5 | 72.9 |
| Sodium hydroxide | 339.0 | 203.4 |
| Potassium hydroxide | 178.0 | 228.0 |

*Note:* Potassium hydroxide, while of most exceptional occurrence, is included on account of the values of its constants as compared with sodium hydroxide.

result of the initial use of sodium carbonate, so that for all of the foregoing reasons sodium hydroxide should (a priori) be considered as the most probable cause of the trouble. It is to be noted also that sodium hydroxide is only very slightly corrosive at boiler temperatures in solution strengths such as occur in the main body of the water in the boiler, but is actually highly corrosive in the stronger solutions that can occur in the joints.

F. B. Porter[8] has drawn the following conclusions from the result of his studies:

> At the University of Illinois, boilers had been operated intermittently for twelve years at 100 pounds pressure on the soft alkaline water without trouble.

[8] Paper read before the American Chemical Society, Tulsa, Okla., April 5, 1926.

Three years' operation at 140 pounds pressure put four drums out of service, and we judge that there were four drums that withstood this same operation that were still unaffected. There is a large number of boilers at Fort Worth, Dallas, Waco, McKinney, Houston, Baton Rouge, Louisiana, and other points that have been operating on soft, alkaline water on pressures from 150 to 210 pounds that have never shown indications of embrittlement. The Trinity sands water in Texas contains enough sulphates to give a sulphate ratio of something like three of sulphates to one of alkalinity, but the other artesian waters used at the plants just mentioned have much less sulphates, some of them only a very small amount. In one plant at Dallas, two plants out of four at Houston, and at one Waco plant an occasional drum has been lost through embrittlement, and in practically every case other drums which have seen the same service with the same water are still in operation, and other plants using the same water have never been affected.

The question of the contributing causes of this peculiar type of embrittlement is important in suggesting remedies and in adjusting a settlement on installations on which renewals are required. This trouble occurs often within six months to three years of the time the boilers are put in service. The cracking occurs in regions of little stress. The actual stress in boiler operation in butt-strap seams is small compared with other sections of the drum. The stresses in the metal set up in the fabrication of the drum in the area adjacent to the rivets may be high. It is a difficult question to decide whether boiler-water leakage into the seams evaporates and produces high concentration and starts embrittlement, or whether the embrittlement and cracking start and the leaks promptly result therefrom. If the leaky condition comes first, it probably does not make very much difference what the concentration of the boiler water is, for the reason that a concentration even to the solid can rapidly occur in the seam as soon as the leak starts.

The impression has been general that it is only overtreated, softened waters that would be likely to cause embrittlement. A recent case of embrittlement where zeolite-treated water only had been used would indicate that any softened water may furnish one of the requisite causes for embrittlement. The mention above of pressures obtaining in boilers and intermittent operation as compared with continuous operation, leads us to make the general observation that we believe that higher pressures and more continuous operation tend to increase the likelihood of embrittlement taking place, but this is as strong as this statement can be made, for some boilers operating under the same pressure and on the same water may be affected and some of them not. One hundred and forty pounds at the University of Illinois, which caused the loss of four drums, is considered a very low water pressure on large plants today.

In conclusion, it seems at the present time that the only explanation of caustic embrittlement that will account for this condition being present in some drums of some plants and absent in other drums of these same plants, and absent in all the drums of other plants, using the same waters and the same type of waters, is that embrittlement is due to overstrained or dirty steel and causticity in contact with same.

Mr. McAdam of the United States Naval Engineering Experiment Station, in a discussion of Professor Parr's paper at the 1926 meeting of the A. S. T. M., reported that he produced intercrystalline cracks in specimens subjected to fatigue tests when he cooled them during the test by directing a jet of water against the specimens.

Mr. Patterson of the Solvay Process Company, in a discussion of Professor Parr's paper (loc cit.), pointed out that caustic soda cannot concentrate very appreciably within the interstices of a seam as long as the seam is tight, since the boiling temperature of a more concentrated solution is higher than that of a more dilute solution, so that as soon as a concentration of the caustic soda solution within the seam rises above that of the main body of water in the boiler, further concentration in the seam stops, since no further evaporation will take place. Therefore it will be impossible to concentrate the solution within the seam to the degree found active by Professor Parr, as long as the seam does not leak. Mr. Patterson has directed attention to the possibility of oxygen in the water as a possible offender accelerating embrittlement.

Mr. Applebaum of the Permutit Company has quoted the work of Mr. Jones:[9]

> In a fresh solution, stressed steel cracked in a few days, but after the solution had been in use for some time the steel became coated with a black deposit of oxide and cracking was inhibited. This is not solely due to the alteration of surface of the steel since the solution now fails to crack fresh similar specimens which are introduced and which themselves become coated much more quickly than the original specimens. A deposit consisting of magnetic oxide and some carbonaceous matter accumulated at the bottom of the vessel. The inhibiting effect of the presence of oxide lends support to the view that cracking is brought about through the agency of hydrogen.

As a result of the experience and extensive experimental work of the Babcock and Wilcox Company, the following conclusions have been drawn by the company concerning this phenomenon and are reported in the 1925–1926 Report of the Prime Movers Committee, N. E. L. A. on Treatment of Feed Water.

Certain characteristics of this cracking are as follows:

1. The cracks all occur below the water level.

2. In at least one of these plants, cracking of boiler drums has continued over a period of at least twelve years. In some cases,

[9] Transactions of the Faraday Society, vol. 17, p. 149.

replacement drums cracked in a shorter period of time, notwithstanding special care in manufacture.

3. All of these cracks have occurred in seams under tension, having factors of safety, as normally calculated, from five to approximately ten.

4. Examination of the type of plate showing cracks has definitely shown that this cracking occurs in plates having practically perfect chemical and physical characteristics, as well as in plates which may not have as good characteristics.

5. These cracks have developed in cast steel, steel boiler plate and most perfect rivet steel.

The characteristics of the cracks themselves in general are:

*a.* They do not follow the line of maximum stress.

*b.* While in general they run from one rivet hole to another, they run more often in entirely different planes, so there will be a crack from one rivet hole passing parallel to a crack from another rivet hole.

*c.* They frequently run from each of two adjacent rivets past each other for at least half their length without joining, or they even cross the full ligament from rivet to rivet without joining, leaving little islands of plate.

*d.* They are irregular in direction when fully developed, having numerous sharp angles, and the final direction of the cracks is sometimes 90 degrees from that at their beginning.

*e.* They never extend into the body of the plate beyond the lap of the plate.

*f.* They sometimes occur on the solid plate of the seam and do not connect with the rivet holes.

*g.* The cracks are not accompanied by elongation of the plate.

*h.* Photomicrographs of these cracks indicate that they are intercrystalline.

*i.* The cracks start on what is usually termed the "dry" face of the joints.

*j.* As stated before, the cracks all occur below the water level of the boiler.

The 1925–1926 report of the Prime Movers Committee, National Electric Light Association on Treatment of Feed Water, contains a statement by the Permutit Company in which they summarize the factors that enter the problem, as follows:

In our opinion there are four factors which must be considered in tracing the origin of cracks in boilers:

*a*. The quality of the steel.

*b*. The stresses either existing in the plate before fabrication, or introduced during fabrication, operation and repair, in addition to the calculated working stresses.

*c*. The temperature to which the steel is exposed when under the total stress and the period of time during which the total stress is acting.

*d*. The composition of the feedwater as well as the boiler salines.

A number of interesting comments have been received, some of which are reported herewith. The president of a firm manufacturing chemical machinery in a letter to the Chairman states as follows:

In the manufacture of caustic soda we find that the eventual failure of what is known as a caustic soda pot is probably due to the continued heating and cooling of the cast-iron pot rather than to definite caustic or chemical action. It is true that we do have some of this caustic or chemical action, but the industry seems to agree fairly well that the reason for the final destruction of caustic soda pots is that continuous heating and cooling of the vessel itself bears the greatest burden of the failure of the casting.

A leading consulting engineer in a letter to the Chairman states:

The full nature of conditions tending to cause caustic embrittlement is far from definitely determined. The evidence while pointing to existence of caustic in solution as probably the most frequent cause, would indicate, however, that caustic by no means occupies a unique position in that respect.

A prominent chemical engineer writes as follows:

I fail to find any direct tie-up between the character of the water and embrittlement. Such tie-up as does exist is based very largely on "hunches," and not on any real data. That is, we know that certain of the water analyzed is poor water for boilers. We deduce, therefore, that this water will produce caustic embrittlement. We examine the boilers and we find cracks and fractures. The boiler even in certain sections may manifest considerable brittleness. We put the two things together and reach the conclusion that the boiler feedwater has been responsible for the cracks and other failures, through the action of caustic embrittlement. Such reasoning may be correct. It does, however, lack the continuity of proof, which we, as engineers, should demand.

An interesting case of embrittlement in a pressure vessel normally containing hot caustic soda in rather high concentrations, was recently called to the attention of the Chairman. This case was very thoroughly investigated and the conclusion reached that the failure

was apparently due to the structure of the plate itself at the time it was fabricated. Microscopic examination showed an almost perfect Widmanstaetten structure (a structure usually formed in cast steel) in the cross-section of the metal. In view of the inherent weakness of this structure, it is doubtful whether the caustic had any influence in causing the failure of the shell.

A leading British metallurgist who has devoted much study to this subject and from whom the Committee requested a statement, has written the Chairman in a private communication as follows:

I do not know of any recent publication in this country bearing on the matter, but I have followed with interest what has been done in America and Germany. With regard to Professors Parr and Straub's paper, I have read it with very great interest and appreciation. While I find some difficulty in believing that a concentration as high as their experiments suggest, can ever be produced in a boiler, even in the fissures or seams, and while I also think that a stress exceeding the yield point can only be caused by the existence of several local stresses due to excessive riveting pressure, etc., I yet feel that their present work has put the matter on a sounder basis than formerly. Their experiments appear to me to establish the fact that caustic soda when sufficiently concentrated can act as an accelerator of cracking in heavily stressed steel. Whether this can be regarded as by any means a full explanation of what occurs in boiler practice, is quite another matter and remains to be established by further work. The only light that I can throw on the whole question is that, so far our experiments—made with a view to producing fracture under prolonged loading in mild steel stressed to various intensities at a temperature of 300 deg. cent. in air—have failed to produce fracture even after a number of years' exposure. This experiment certainly suggests that some subsidiary agency of a corrosive nature is necessary to produce failure in a reasonable time, although it is quite possible that the particular sample of steel which I employed was not one subject to intercrystalline fracture under prolonged loading. There is to my mind no doubt at all that the nature and condition of the steel plays a large part in the matter.

The only immediate suggestion I can offer is that experiments on the lines of those made by Parr and Straub should be carried out on steels of different origin, particularly on acid as well as basic steels and after various forms of heat treatment, including a heat treatment which shall render the carbide granular or spherulitic instead of lamellar.

A consulting engineer of prominence, who has had over forty years' experience in chemical and mechanical engineering, has furnished the Committee the following opinion relating to the problem of embrittlement.

The cases of embrittlement which have come under my observaton have been so contradictory that I am led to believe that only certain qualities of

steel are affected. By quality I mean physical quality. The chemical analysis seems to throw no light on this subject, and in the same apparatus one sheet of steel will develop minute cracks, which in many cases are in the middle of a sheet, while other sheets in the same apparatus and under the same conditions, last indefinitely.

I have never known any case of embrittlement in boiler shells or steam drums of boilers, except with very concentrated liquors. I once tried the use of a water-tube boiler for concentrated caustic liquor from 20° to 30°B. These boilers gave no trouble while in this service for a period of several months, but after being returned to ordinary boiler service, I found one of the seams of one of the drums had a crack along the calking of the longitudinal seam nearly three feet long, and the inside had a number of minute cracks extending from one rivet hole to the others, sometimes in two or three directions. This seam was cut out, taken apart and examined very carefully. The water was being treated with soda ash and lime and contained a small amount of caustic soda which was, however, not allowed to concentrate very much, but it was evident that if the water could leak into the space between the laps which were not very well drawn together, the caustic might concentrate in that particular seam and have an action on the steel which would not be possible with the low concentration.

Following this were several others of a similar kind, where the drums had been used for concentrate caustic liquor and cracks were found by examination with a microscope in a number of other drums, always in the seams between rivet holes where the joints had been pulled together with drift pins, or where the severe calking had been done.

I have also noticed that steel tanks containing hot 40°B. liquor are gradually embrittled, especially in the seams. When struck with a hammer, after these tanks have been long in use, the rivet heads will pop off, showing in many cases cracks which are part way through the rivets, which had evidently been there a long time, but alongside of them were other tanks with 20°B. liquor that had been in use for thirty-five years, some of them wrought iron, some steel, which were not affected.

I have noticed in some cases where cast-iron pipe joints are held together with bolts and slight leaks of caustic liquor occurred, which ran over the bolts, that these bolts were broken in two in two places, or many of them half-broken in two. In one case of a large B. & W. "W"-type boiler, a lower drum developed some cracks in one sheet. Six other boilers running under the same conditions gave no trouble. A spare drum was ordered which has never been put in, and while the failure was laid by the manufacturers to embrittlement, and several learned reports were written on the subject, I have never been satisfied that the cracks were caused by the very slight amount of caustic soda present in the water.

Professor Baumann in a lecture before the Association of Steam Boiler Inspectors at Zurich, Switzerland, on September 7, 1926, stated that the evidence from laboratory tests indicated that the presence of caustic soda is not essential to the formation of intercrystalline cracks.

Dr. Guilleaume in a recent report[10] stated that in all cases where steel failed in service, the failures were traced to thermal and mechanical causes. In no instance was it indicated that caustic soda had been responsible for the development of the fracture of the metals.

Last year, two important[11] contributions on this subject appeared in Germany. Dr. Bauer, of the Metallographical Institute of Dahlem, has shown that hydrogen in contact with metal and under high pressure (up to 3000 pounds) will not affect the strength of the metal when the contact takes place at room temperatures. Dr. Bauer has demonstrated, however, that relatively small amounts of hydrogen in contact with iron or steel at boiler temperatures are readily absorbed by the metal, materially reducing its tensile strength.

Professor Thiel's research studies have shown that 77.5 per cent of caustic soda may concentrate in the clearances between the boiler plates, resulting in reducing the tensile strength of the boiler. This action, according to Professor Thiel, is due to the absorption of hydrogen which is released from the caustic soda when the sodium unites chemically with the iron.

An enlightening editorial on the subject of embrittlment appeared in *Power* in the August 17, 1926, edition of this periodical. A portion of this comment is quoted since it confirms the Committee views that future research is highly desirable.

> Are there not several kinds of causes for embrittlement? Are all embrittlement cracks from the same cause? The boiler user is intensely interested in the answers to such questions.
>
> But the boiler user cannot be content to sit idly awaiting the conclusions of what is to him in a measure an academic question. After all, he cares little by what name his trouble is called. His demand is for some remedy that will enable him to operate safely. Whether the remedy is scientifically rational or purely empirical is interesting, but not vital to him. Even a "hunch" is good enough for him if it works. True, there may be a cheaper and better way to be developed through further research, and this the operator wants, but he dare not wait for it. He must do something now.
>
> What shall he do? Two factors are involved—stress and water conditions. Perhaps the elimination of either alone will cure the disease, but since both are under suspicion, why not do all that can be done to eliminate both? Severe internal stress is admittedly bad on all counts. Let every effort be made to

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[10] Report presented to the Association of Large Steam Boiler Plants at Cassel, Germany, September 17, 1926.

[11] Papers read at the Association of Owners of Large Boilers at Darmstadt, December, 1925.

eliminate it by insisting on first-rate material and the best possible shop practice. Certain materials in solution in the feedwater seem also, in some instances at least, to be a contributing cause. Let care be taken in adding such things to the water or in neutralizing them if they are already present.

Your Committee has attempted to summarize the work of the various investigators and to present the viewpoint of those who have advanced the theory of embrittlement due to high concentrations of caustic soda and that of those rejecting this premise. The latter call attention to the following phenomena which may influence the failures.

Gaseous hydrogen from any source may penetrate steel and be occluded by it, resulting in embrittlement of the metal. This phenonenon may take place not only from caustic soda but from any other source. Excessive strains set up in the metal may be the primary cause for embrittlement and the source of intercrystalline cracking. Intercrystalline cracks may be developed in ferrous and non-ferrous metal due to improper thermal treatment in the manufacture of the metal.

The advocates of caustic embrittlement tend to direct attention to the quality of water as the offending agent rather than the material in the boiler or the method of fabricating the equipment. Failures of this kind have occurred largely in certain sections of the country where the water used for boiler feed contains relatively large quantities of sodium carbonate and bicarbonates and is low in sulphates or chlorides. In many instances, the difficulty has disappeared entirely by changing the source of the feedwater and using water that did not have these characteristics or by treating the water chemically so as to maintain a predetermined ratio between the carbonates and sulphates.

The difficulty has not been confined to boilers of any one manufacturer, thereby tending to eliminate the theory of faulty design and construction or dirty metal. Embrittlement of metal has been produced by investigators by duplicating conditions that theoretically should be favorable to producing the characteristic intercrystalline cracking of the metal.

A complete bibliography of the subject of embrittlement of metals has been prepared by the Engineering Library, 29 W. 39th Street, New York, copies of which can be secured for a nominal charge by any one interested in this subject.

## RECOMMENDATIONS

Most of the experimental work which has been carried on has been with waters high in carbonate or bicarbonate of soda. Little information is available concerning the possibility of embrittlement of boiler metal in waters low in these salts. It has already been demonstrated in one case reported to the Committee that embrittlement of boilers may and has resulted from the use of feedwater low in sodium salts.

Little information is available concerning the effect of dissolved gases in accelerating the phenomenon of embrittlement.

High pressure as a contributing agent has not been established. There are many other factors entering into the problem which up to the present time have received no special attention from investigators of these problems. It is evident that there is much still to be learned concerning the cause or causes of intercrystalline cracking of boiler plate and much is to be learned concerning the methods of controlling the contributing factors.

The preceding paragraphs present a brief digest of the great mass of data submitted to the Committee. A careful study of all of this material has led to the formulation of the following recommendations:

1. In view of the wide diversity of opinion on the cause of embrittlement, extensive research should be started to determine the influence of all possible contributing factors.

2. Plans for such research should be formulated to give cognizance to causes of embrittlement other than those which may result from the use of waters in which high concentration of caustic soda is potentially possible.

3. Not only must the causes of embrittlement be determined, but means of preventing its occurrence under all conditions should be developed as soon as all contributing causes are known.

4. Since the plate ligament or the rivets in riveted joints may be stressed beyond the elastic limit of the metal, a study of other means of joining plates such as welding, is a logical step in the elimination of embrittlement troubles.

5. This research may be carried out in University laboratories, but funds must be obtained to finance this experimental work.

6. This Committee should be continued to coördinate the research work and to report developments in the study of Embrittlement of Metals.

# MUNICIPAL WATER SUPPLIES AND THE EFFECT OF TRADE WASTES IN RELATION TO THE USE OF WATER IN POWER-PLANT PRACTICE

## Progress Report of Sub-Committee No. 7 on Municipal Water Supply in Relation to Boiler Use[1]

By V. Bernard Siems, *Chairman*

The activities of this Committee during the past year have been devoted to two distinct problems affecting the treatment of water for steam-making uses and for condenser purposes.

*a.* Collection of data relative to the quality of water supplied by municipalities and its effect on the cost of operation of industrial water treatment systems.

*b.* A study of the effect of trade wastes and domestic sewage discharged into surface streams used as a source of supply for power-plant uses.

[1] The personnel of Sub-Committee No. 7, on Municipal Water Supply in Relation to Boiler Use, of the Joint Research Committee on Boiler Feedwater Studies is as follows:

V. Bernard Siems, *Chairman*, Water Engineer, City Hall, Baltimore, Md.

W. R. Abbott, Chief Engineer, Commonwealth Edison Company, Chicago, Ill.

A. J. Authenreith, Vice-President, Middle West Utilities Company, Chicago, Ill.

Edward J. Billings, Vice-President, Fuller-Lehigh Co., Fullerton, Pa.

John H. Buell, Manager of Operations, Oklahoma Power Company, Tulsa, Okla.

W. D. Collins, U. S. Geological Survey, Washington, D. C.

Charles Fox, Assistant Superintendent, Pennsylvania Water Company, Wilkinsburg, Pa.

C. P. Hoover, Chemist and Superintendent, Water and Sewage Department, Columbus Filter Plant, Columbus, O.

Nicholas S. Hill, Jr., President, Hackensack Water Company, Hackensack, N. J. and Consulting Engineer, New York, N. Y.

B. N. Randolph, Water Purifying Department, William B. Scaife and Sons Company, Oakmont, Pa.

Caleb M. Saville, Manager and Chief Engineer, Water Works, 53 North Beacon Street, Hartford, Conn.

Early last year a questionnaire was sent out to a large number of companies for information concerning these problems. The results of this inquiry indicated clearly that the treatment of municipal water supplies does not, in most cases, seriously affect its value for steam-making uses. There is a tendency, however, on the part of some municipal water treatment plant operators to lose sight of the industrial users' requirements, provided the sanitary requirements for the safe quality of the water are fulfilled. This is indicated by the increasing popularity of the procedure of adding sulphuric acid to water prior to alum, to increase coagulation, and to the inhibition of corrosion by the addition of lime to the filtered water. There is apparently a complete lack of knowledge by most engineers responsible for the treatment of water for industrial use, concerning these conditions. There are no data available as to the effect of such treatment on the cost of operation of privately owned water-purification plants.

Preliminary studies by the Committee indicates that these problems are of sufficient importance to be given consideration and require further study.

Considerable apathy apparently exists concerning the detrimental effect of trade waste on the operation and maintenance of power-plant equipment. Excepting in certain areas, particularly in Pittsburgh and some other districts, little effort has been made to cope with the problem.

One company situated in a highly developed industrial area has furnished the Committee with considerable detailed information concerning corrosion problems at its plant. A portion of their report is as follows:

> Our trouble has been due to acid coming from the pickling baths of a steel mill. This acid forms a hard oxide scale on the condenser tubes that seriously impairs our vacuum. This scale is so hard that the only effective method for its removal is the hydrochloric-acid-bath treatment.
>
> The acid in the water has eaten out our feed lines, impellers, strainers, etc. We are now just renewing completely the entire auxiliary feed lines. The old lines taken down were very badly eaten through, and all contained blisters and pockets.

The cost of cleaning the condensers at this plant is over \$5000 yearly.

The effect of oil-refinery sludge on condenser operation is indicated in the following statement furnished by a large power company in the Middle West.

The plant is located at a point below several oil refineries. These refineries discharge into the river certain oil sludges which carry acid. We have had to retube our condensers, and to date have not been able to determine whether the pitting or corrosion, which goes on in the condenser tubes, is due to the chlorine or alkaline character of the water or if it is assisted by the acid contained in the oil sludge, which latter substance deposits on the inside of the condenser tubes.

Replies from five companies using river water contaminated with oil sludge reported serious trouble from corroded condenser tubes and reduced vacuum as a result of sludge accumulation on the inside of the tubes. Two reported priming and foaming of boilers as a result of oil, although both companies used filters and softening plants to treat the feed water. At one plant the boiler-tube losses were excessive and these failures are traced directly to the presence of oil.

It is also quite apparent that domestic sewage, discharged into water courses used for cooling water in surface condensers, has a very detrimental effect. Several large companies on the Atlantic seaboard report that they can trace poor condenser efficiency and the majority of their condenser failures to this source.

The Committee submits this progress report merely to direct attention to the magnitude of the problem and makes the following recommendations:

1. Continuation of the Committee and expansion and coöperation with various state and governmental bureaus which are giving consideration to these problems.

2. Constructive research leading toward more efficient methods of treatment for the removal of trade waste from feedwater.

3. A comprehensive study of existing laws and ordinances relating to the prohibition of trade-waste pollution of streams used for feedwater or cooling-water purposes.

The Committee has established relations with the Trade Wastes Committee of the American Water Works Association and has arranged for an interchange of data relating to these problems.

## WATER CONSUMPTION FOR VARIOUS PURPOSES IN TERMS OF DEPTH AND AREA[1]

By Charles H. Lee[2]

Rapid growth is characteristic of most American communities. This is especially true of those in industrial districts and in the rapidly developing western states, such as California. The normal population growth for the average American city is 20 to 30 per cent each decade, but for the average California city it is at least 50 per cent. Half of the cities of the state with 8000 or more population in 1920, experienced an increase of more than 75 per cent during the decade 1910 to 1920, and several of them doubled, and one even trebled in size.

These phenomenal growths bring added responsibility to the management of water work properties. For example, it is often found desirable to design and build major structures for the ultimate supply in order to meet the requirements of economy in cost. In semi-arid and arid regions where the supply is limited and there is probability of its use for other purposes, expenditures for water-rights and lands become necessary long in advance of actual need. It is quite common to find large cities looking ahead forty to fifty years in their water works construction programs, and, where located in regions of limited supply, the acquisition of lands and water-rights from seventy-five to one-hundred years in advance is not unusual.

The problem of determining the amount of water which will be required for future needs presents itself whenever any step is taken to provide additional water supply. It is the usual practice when estimating the requirements of an anticipated population to project forward the current rate of growth and apply to it per capita consumption based on present experience, as modified by probable changes in the character and amount of use. This method gives results sufficiently reliable for short periods and under ordinary conditions where domestic and public use predominate, or where expan-

[1] Presented before the California Section meeting, October 29, 1926.

[2] Consulting Hydraulic Engineer, San Francisco, California.

sion without radical change in the character of use is to be expected. A growing number of communities, however, show a tendency toward increase in demands of a character that cannot be readily determined on a basis of population and per capita consumption. Among such demands may be listed the use of water for industrial purposes, which often represents an important part of the total draft upon a water system. There is also the increased demand for water resulting from the tendency of modern cities to extend their borders beyond the built-up limits, thus adding much land devoted to commercial gardening, as well as tracts laid out as suburban residence property. In arid and semi-arid regions such areas require much water for irrigation. The amount of water required for either industrial or irrigation purposes bears no direct relation to population, and its use as a divisor is entirely arbitrary. Many of the instances of apparent abnormally high rate of consumption are due to relatively small population and large industrial or other special demand.

Perhaps the most complex of all problems of this character which water works officials and engineers are called upon to answer, is the future water requirement of metropolitan areas. Such areas will always be composed of distinctive units, some urban or suburban residential, some commercial or industrial, and some rural or recreational. Each will have different water requirements, the amount of which in many cases will be wholly unrelated to the number of individuals resident upon such areas. This problem has already come to the front in California in the Metropolitan Districts of Los Angeles and San Francisco-Oakland, and will later arise in the metropolitan areas which are beginning to surround San Diego and other rapidly growing cities. Recreational areas such as those about Monterey Bay and Santa Barbara also have this problem to meet.

There has thus arisen a definite need for some simple basis of estimating, other than population, which can be applied to all varieties of use and yet be related to some common factor. The problem has presented itself to the writer on several occasions and much thought had been given to it. As a solution, it is proposed to use area as the common factor instead of population, with equivalent depth of water delivered to the area as the measure of the requirement. This method has long been established in irrigation practice, the amount of water used being expressed as depth over the cropped area, the term "water requirement" or "duty of water" having come extensively into use in this connection. The area being served by a given water

works system and the quantity of water delivered both being easily obtainable, it would seem feasible to determine the depth used per unit area, whether the use be for general municipal or for industrial or irrigation purposes. Analysis of water works statistics on this basis seems not only to yield results of value for use in estimating future consumption, but also to furnish a new and useful basis for comprehensive analysis and comparison of such statistics.

The mathematical relations of per capita consumption and depth can be very easily expressed in a formula which includes population density. If

$Q$ = total annual water consumption in gallons
$C$ = daily per capita consumption in gallons
$A$ = area served in acres
$P$ = population
$p$ = population density
$D$ = depth of water in feet per annum consumed upon service area

Then

$$D = \frac{Q}{A \times 325{,}850} = p\,C/890$$

and

$$C = 890\,D/p$$

In other words, the depth of water consumed per annum upon a given service area is directly proportional to both population density and per capita water consumption, while per capita consumption is directly proportional to depth of water consumed and inversely proportional to population density. By means of these equations, if population density is known, it is possible to convert per capita statistics into depth, and vice versa.

This paper gives the results of determinations of the depth of water used per acre per annum in general municipal service and in special services, for various American cities. It also illustrates a new method for analysis of water consumption data, which, it is believed, will be suggestive to both water works officials and the engineering profession. The writer desires to acknowledge and express his appreciation of the assistance furnished by various water works officials in California who were asked to furnish data. It is hoped that the paper will serve to bring forth additional information on this subject and help to stimulate the systematic reporting of the acreage of service areas.

## WATER CONSUMPTION STATISTICS

The consumption of water from public water works systems, whether municipally or privately owned, includes both that used for domestic and public purposes, and for the needs of business and industry. It also includes loss and waste from distribution systems and service connections. In the average American city practically all domestic water is furnished from the public supply, and as the amount depends directly upon the number of people using water, it can be readily expressed on a per capita basis. An average for the United States under modern conditions is considered to be 30 to 35 gallons per capita per day, although where garden and lawn irrigation is practiced, as in California, this amount may be considerably exceeded. To this should be added public use for fire protection, sewer flushing, street sprinkling, parks, etc., varying from 5 to 10 gallons per capita per day in various cities. The minimum demand upon any water works system may thus be considered as from 35 to 45 gallons per capita for the population within the service area, plus the requirements for gardens and lawns in regions where irrigation is necessary.

The use of water for commercial and industrial purposes is in addition to this minimum and varies greatly in different cities, particularly that for industrial operations. This variation is due to the differences in manufacturing processes, the differing extent to which industries are established and the extent to which local sources are in use. In connection with the latter, the relative cost of water from the public system and from local sources, such as wells, is the important controlling factor. In cities where local sources are cheaply developed and pumping plants can be operated at small cost in conjunction with other equipment, the industrial demand upon a public water system is small. On the other hand, where the public supply is furnished for industrial use at a low rate, or local sources are not available, practically all such users within the city draw from the public supply. The percentage which commercial and industrial use bears to the total is therefore extremely variable, statistics indicating a range of from 15 to 65 per cent. These facts are all well known to water works men, but are so pertinent to the analysis of statistics which follows that emphasis seem desirable.

## DEPTH OF WATER IN GENERAL MUNICIPAL SERVICE

Separate study has been made of the depth of water in general municipal service, and in special services such as domestic, com-

## TABLE 1

*Summary of water consumption data for 95 American cities, 80 per cent or more services metered*

| NUMBER | CITY | AREA SERVED* | POPULATION ‡ | | WATER CONSUMPTION | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Total | Per acre | Total million gallons per day ‡ | Per capita gallons per day | Per acre gallons per day | Per acre annual depth in feet |
| | | *acres* | | | | | | |
| 1 | Atlanta, Ga. | 19,635 | 276,000 | 14.1 | 26 | 95 | 1,320 | 1.48 |
| 101 | Altoona, Pa. | 2,654 | 65,000 | 24.6 | 4,094 | 63 | 1,550 | 1.74 |
| 103 | Albany, N. Y. | 11,924 | 130,000 | 10.9 | 19,515 | 150 | 1,644 | 1.84 |
| 104 | Akron, Ohio | 15,990 | 208,435§ | 13.0 | 16,510 | 79 | 1,028 | 1.15 |
| 105 | Beaumont, Texas | 6,464 | 55,000 | 8.5 | 3,500 | 64 | 544 | 0.61 |
| 106 | Binghampton, N. Y. | 5,991 | 76,000 | 12.7 | 6,100 | 80 | 1,016 | 1.14 |
| 2 | Boston, Mass. | 27,635 | 788,000 | 28.5 | 87.7 | 114†† | 3,180 | 3.56 |
| 3 | Brockton, Mass. | 13,678 | 84,000 | 6.1 | 4.2 | 45†† | 307 | 0.34 |
| 107 | Cicero, Ill. | 3,678 | 70,000 | 19.0 | 6,500 | 93 | 1,768 | 1.98 |
| 108 | Cedar Rapids, Iowa | 7,805 | 52,000 | 6.7 | 4,475 | 86 | 576 | 0.65 |
| 109 | Covington, Ky. | 3,837 | 57,121§ | 14.9 | 5,500 | 96 | 1,430 | 1.60 |
| 110 | Charlotte, N. C. | 8,167 | 60,000 | 7.4 | 4,300 | 72 | 533 | 0.60 |
| 111 | Canton, Ohio | 8,029 | 102,000 | 12.8 | 13,000 | 127 | 1,625 | 1.82 |
| 112 | Chester, Pa. | 3,020 | 58,030§ | 19.2 | 7,500 | 129 | 2,480 | 2.78 |
| 113 | Charleston, S. C. | 2,873 | 67,957§ | 23.6 | 5,600 | 83 | 2,030 | 2.28 |
| 4 | Chelsea, Mass. | 1,191.6 | 47,000§ | 39.4 | 3.55 | 76 | 2,980 | 3.34 |
| 5 | Cleveland, Ohio | 43,929 | 1,074,000 | 24.4 | 151.2 | 143†† | 3,440 | 3.85 |
| 6 | Cincinnati, Ohio | 45,598 | 425,000 | 9.3 | 48.9 | 116†† | 1,070 | 1.20 |
| 7 | Columbus, Ohio | 16,475 | 270,000 | 16.4 | 23.2 | 87†† | 1,410 | 1.58 |
| 8 | Dayton, Ohio | 10,107 | 170,000 | 16.8 | 16.7 | 98 | 1,652 | 1.85 |
| 115 | Des Moines, Iowa | 33,597 | 140,000 | 4.2 | 11,818 | 85 | 357 | 0.40 |
| 116 | Davenport, Iowa | 10,393 | 61,000 | 5.9 | 4,800 | 79 | 466 | 0.52 |
| 117 | Duluth, Minn. | 39,917 | 100,000§ | 2.5 | 9,978 | 100 | 250 | 0.28 |
| 9 | Detroit, Mich. | 54,175 | 1,372,000 | 25.4 | 18.4 | 141†† | 3,400 | 3.81 |
| 10 | Dallas, Texas | 16,539 | 229,000 | 13.9 | 13 | 56 | 785 | 0.88 |
| 118 | East Chicago, Ind. | 6,396 | 50,000 | 7.8 | 5,500 | 110 | 860 | 0.96 |
| 119 | Evansville, Ind. | 5,577 | 85,264§ | 15.3 | 8,500 | 100 | 1,530 | 1.72 |
| 120 | El Paso, Texas | 8,640 | 82,500 | 9.5 | 7,300 | 88 | 836 | 0.94 |
| 11 | East Bay Cities, Calif. | 37,000† | 498,000** | 13.5 | 29.5** | 59 | 796 | 0.89 |
| 12 | Everett, Mass. | 2,151 | 44,000 | 20.4 | 4.5 | 102 | 2,090 | 2.34 |
| 121 | Flint, Mich. | 18,140 | 130,000 | 7.2 | 14,000 | 108 | 778 | 0.87 |
| 122 | Fort Worth, Texas | 24,761 | 160,000 | 6.5 | 10,000 | 63 | 410 | 0.46 |
| 13 | Fall River, Mass. | 21,051 | 131,000 | 6.2 | 6.8 | 52†† | 323 | 0.36 |
| 14 | Grand Rapids, Mich. | 11,211 | 160,000 | 14.3 | 15.9 | 100†† | 1,420 | 1.59 |
| 123 | Gary, Ind. | 25,172 | 75,000 | 3.0 | 5,500 | 73 | 219 | 0.25 |
| 125 | Houston, Texas | 25,924 | 138,276§ | 5.3 | 12,000 | 87 | 461 | 0.52 |
| 126 | Harrisburg, Pa. | 3,861 | 82,849 | 22.0 | 11,403 | 138 | 3,040 | 3.41 |
| 127 | Hoboken, N. J. | 830 | 68,166§ | 82.0 | 7,500 | 110 | 9,025 | 10.12 |
| 15 | Hartford, Conn. | 10,163 | 182,000 | 17.9 | 16.2 | 85†† | 1,590 | 1.78 |
| 128 | Jacksonville, Fla. | 9,824 | 100,000§ | 10.2 | 10,000 | 100 | 1,020 | 1.14 |
| 129 | Jackson, Mich. | 5,653 | 52,000§ | 9.2 | 4,959 | 95 | 875 | 0.98 |
| 130 | Kalamazoo, Mich. | 5,285 | 54,900 | 10.4 | 4,393 | 80 | 832 | 0.93 |
| 132 | Kansas City, Kan. | 12,040 | 120,000 | 10.0 | 16,000 | 133 | 1,330 | 1.49 |
| 16 | Kansas City, Mo. | 37,395 | 384,000 | 10.3 | 48.3 | 134†* | 1,290 | 1.45 |

*Note:* Data for cities numbered 1 to 46 from JOURNAL OF THE AMERICAN WATER WORKS ASSOCIATION, January 1926, pp. 1–21. Data for cities numbered 101 to 157 from 1925 and 1926 Municipal Index.

* Land area within political boundary, July 1, 1923, from Financial Statistics of Cities, U. S. Census Bureau—except as marked †.

† Service area.

‡ Population served and total water consumption as of 1924—except as marked § and **.

§ Population as of U. S. Census 1920.

** Data as of 1925.

†† Average of five years 1920–1924.

## TABLE 1—*concluded*

| NUMBER | CITY | AREA SERVED* | POPULATION ‡ | | WATER CONSUMPTION | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Total | Per acre | Total million gallons per day ‡ | Per capita gallons per day | Per acre gallons per day | Per acre annual depth in feet |
| | | *acres* | | | | | | |
| 17 | Los Angeles, Calif. | 80,960† | 1,100,000** | 13.6 | 126.0** | 109†† | 1,555 | 1.74 |
| 18 | Lawrence, Mass. | 4,317 | 103,000 | 24.0 | 4.6 | 46†† | 1,065 | 1.19 |
| 19 | Lowell, Mass. | 8,566 | 125,000 | 14.6 | 6.5 | 57†† | 765 | 0.86 |
| 133 | Lansing, Mich. | 7,082 | 74,000 | 10.4 | 6,500 | 88 | 916 | 1.03 |
| 134 | Lincoln, Neb. | 8,021 | 54,948§ | 6.8 | 5,333 | 99 | 673 | 0.76 |
| 135 | Lakewood, Ohio | 3,474 | 55,000 | 15.8 | 4,000 | 73 | 1,153 | 1.30 |
| 22 | Malden, Mass. | 3,252 | 53,000 | 16.3 | 2.86 | 54 | 880 | 0.98 |
| 21 | Medford, Mass. | 5,253 | 46,000 | 8.8 | 2.4 | 53 | 460 | 0.52 |
| 20 | Mass. Metro. Dist. | | | | 124.1 | 97 | | |
| 23 | Milwaukee, Wis. | 16,885 | 550,000 | 32.6 | 69.0 | 128†† | 4,090 | 4.58 |
| 24 | Minneapolis, Minn. | 31,834 | 417,000 | 13.1 | 42.8 | 102†† | 1,340 | 1.50 |
| 25 | Manchester, N. H. | 20,520 | 83,000 | 4.0 | 6.4 | 71†† | 312 | 0.35 |
| 26 | Madison, Wis. | 4,109 | 48,000 | 11.7 | 4.8 | 102†† | 1,168 | 1.31 |
| 27 | Memphis, Tenn. | 14,994 | 201,000 | 13.4 | 14 | 70 | 934 | 1.04 |
| 28 | New Orleans, La. | 113,920 | 412,000 | 3.6 | 45.4 | 110 | 398 | 0.44 |
| 29 | Newark, N. J. | 14,913 | 446,000 | 30.0 | 43.6 | 99†† | 2,920 | 3.25 |
| 30 | New Bedford, Mass. | 12,153 | 145,000 | 11.9 | 9.7 | 73†† | 800 | 0.90 |
| 136 | New Britain, Conn. | 8,519 | 61,000 | 7.2 | 6,000 | 98 | 706 | 0.79 |
| 138 | Oak Park, Ill. | 2,880 | 50,000 | 17.4 | 4,000 | 80 | 1,392 | 1.56 |
| 139 | Omaha and Benson, Neb. | 23,686 | 203,000 | 8.6 | 25,500 | 126 | 1,083 | 1.21 |
| 140 | Pawtucket, R. I. | 5,494 | 69,000 | 12.6 | 10,120 | 147 | 1,852 | 2.08 |
| 141 | Patterson, N. J. | 5,157 | 142,000 | 27.5 | 10,000 | 71 | 1,950 | 2.18 |
| 31 | Providence, R. I. | 11,410 | 284,000 | 24.9 | 23.6 | 82†† | 2,070 | 2.32 |
| 32 | Quincy, Mass. | 10,567 | 53,000 | 5.0 | 4.4 | 82 | 417 | 0.47 |
| 33 | Richmond, Va. | 15,360 | 180,000 | 11.7 | 20 | 108 | 1,287 | 1.44 |
| 34 | Rochester, N. Y. | 20,565 | 309,000 | 15.1 | 26.4 | 90†† | 1,285 | 1.44 |
| 142 | Racine, Wis. | 3,858 | 64,000 | 16.6 | 5,074 | 79 | 1,312 | 1.47 |
| 143 | Springfield, Ill. | 5,532 | 71,835 | 13.0 | 6,887 | 96 | 1,248 | 1.40 |
| 144 | Syracuse, N. Y. | 11,379 | 188,000 | 16.6 | 26,500 | 135 | 2,240 | 2.51 |
| 145 | Scranton, Pa. | 12,362 | 141,000 | 11.4 | 25,000 | 171 | 1,950 | 2.18 |
| 146 | Spokane, Wash. | 25,075 | 110,000 | 4.4 | 23,000 | 209 | 920 | 1.03 |
| 147 | Sioux, Iowa | 28,020 | 80,000 | 2.9 | 6,000 | 75 | 218 | 0.24 |
| 148 | Shreveport, La. | 8,486 | 65,000 | 7.7 | 5,100 | 79 | 608 | 0.68 |
| 36 | Somerville, Mass. | 2,518 | 101,000 | 40.1 | 7.8 | 77 | 3,100 | 3.47 |
| 35 | St. Paul, Minn. | 33,388 | 280,000 | 8.3 | 20.4 | 79†† | 610 | 0.68 |
| 37 | Springfield, Mass. | 20,286 | 151,000 | 7.5 | 13.5 | 91†† | 640 | 0.72 |
| 38 | San Francisco, Calif. | 16,170† | 610,000 | 37.7 | 39.3 | 65†† | 2,450 | 2.74 |
| 39 | Seattle, Wash. | 43,840 | 378,000 | 8.6 | 40 | 105 | 915 | 1.02 |
| 40 | Taunton, Mass. | 30,266 | 37,000 | 1.2 | 3.6 | 99 | 119 | 0.13 |
| 41 | Toledo, Ohio | 18,440 | 283,000 | 15.4 | 29.0 | 104†† | 1,570 | 1.76 |
| 150 | Terre Haute, Ind. | 5,759 | 66,083§ | 11.4 | 5,000 | 76 | 867 | 0.97 |
| 151 | Topeka, Kan. | 5,460 | 60,000 | 11.0 | 7,000 | 117 | 1,290 | 1.45 |
| 152 | Utica, N. Y. | 13,404 | 105,000 | 7.8 | 9,500 | 91 | 710 | 0.80 |
| 154 | Wilmington, Del. | 4,495 | 117,727 | 26.2 | 13,638 | 116 | 3,040 | 3.41 |
| 156 | Wachita Falls, Texas | 6,788 | 55,000 | 8.1 | 4,500 | 82 | 665 | 0.74 |
| 42 | Woonsocket, R. I. | 5,532 | 51,000 | 9.2 | 3.1 | 54†† | 560 | 0.63 |
| 43 | Waltham, Mass. | 7,940 | 33,000 | 4.2 | 2.2 | 65†† | 277 | 0.31 |
| 44 | Worcester, Mass. | 23,782 | 192,000 | 8.0 | 16.3 | 86†† | 685 | 0.77 |
| 45 | Washington, D. C. | 39,680 | 486,000 | 12.2 | 64 | 132 | 1,610 | 1.80 |
| 46 | Yonkers, N. Y. | 12,880 | 110,000 | 8.5 | 13.4 | 113†† | 1,040 | 1.16 |
| 157 | Youngstown, Ohio | 16,224 | 145,000 | 9.0 | 12,500 | 86 | 773 | 0.87 |
| Totals | | | 17,829,091 | | | 8,972 | | |
| Average—95 cities | | | | | | 95 | | |

mercial and industrial. For general service, the data available are limited to the total volume of water consumed for all purposes as contained in routine water works reports. The recent files of the Journal of the American Water Works Association and Municipal Index for 1925 and 1926 were extensively referred to in obtaining such information. Data for many California cities were also obtained by correspondence. It has never become customary to report service area acreage, and such information can only be obtained by

TABLE 2

*Summary of water consumption data for 8 American cities, 25 per cent or less services metered*

| NUMBER | CITY | AREA SERVED | POPULATION | | WATER CONSUMPTION | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Total | Per acre | Total million gallons per day | Per capita gallons per day | Per acre gallons per day | Per acre annual depth in feet |
| | | *acres* | | | | | | |
| 1 | Buffalo, N. Y. | 24,890 | 550,000 | 22.1 | 119 | 213 | 4,780 | 5.35 |
| 2 | Baltimore, Md. | 27,634 | 797,000 | 28.8 | 105 | 132 | 3,800 | 4.25 |
| 3 | Chicago, Ill. | 124,604 | 3,015,000 | 24.2 | 806 | 275 | 6,470 | 7.25 |
| 4 | Denver, Colo. | 37,085 | 335,000 | 9.9 | 61 | 191 | 1,650 | 1.85 |
| 5 | Indianapolis, Ind. | 29,688 | 362,000 | 12.2 | 32.4 | 90 | 1,090 | 1.22 |
| 6 | New York, N. Y. | 191,360 | 6,015,000 | 31.5 | 789.2 | 129 | 4,120 | 4.61 |
| 7 | Philadelphia, Pa. | 81,920 | 1,914,000 | 23.3 | 323 | 168 | 3,950 | 4.43 |
| 8 | St. Louis, Mo. | 39,040 | 811,000 | 20.8 | 113.1 | 140 | 2,870 | 3.21 |
| Totals | | | 13,799,000 | | | 1,338 | | |
| Average | | | | | | 167 | | |

Data from Journal of the American Water Works Association, January, 1926, pp. 1–21.

direct contact with department officials. This has been done in the case of many California cities. For cities in other states which were not so obtained, the land area within municipal boundaries, as published in the latest annual reports of the United States Census Bureau, have been used.[3] This area does not in all cases represent water works service area, but it is believed to be sufficiently accurate for

[3] Financial Statistics of Cities, U. S. Census Bureau 1923, Table 1, and various bulletins.

TABLE 3

*Summary of water consumption data for California cities—1924 and 1925*

| NUMBER | CITY | AREA SERVED* | POPULATION: Total | POPULATION: Per acre | WATER CONSUMPTION: Total million gallons per year | WATER CONSUMPTION: Per capita gallons per day | WATER CONSUMPTION: Per acre gallons per day | WATER CONSUMPTION: Per acre annual depth in feet | PER CENT METERED |
|---|---|---|---|---|---|---|---|---|---|
| | | *acres* | | | | | | | |
| 101 | Alhambra | 4,060 | 25,000 | 6.15 | 1,645 | 66 | 406 | 0.46 | 100 |
| 1 | Belvedere Water Corporation | 3,840 | 50,000 | 13.0 | 842 | 46 | 607 | 0.68 | |
| 2 | East Bay Cities | 37,000 | 498,000 | 13.5 | 10,766 | 59 | 796 | 0.89 | 100 |
| 102 | Eureka | 3,731 | 20,000 | 5.36 | 1,500 | 75 | 402 | 0.45 | 98 |
| 103 | Fresno | 5,432 | 72,000 | 13.3 | 17,500 | 244 | 3,246 | 3.64 | 8 |
| 3 | Glendale | 7,000 | 48,500 | 6.9 | 1,706 | 96 | 670 | 0.75 | |
| 104 | Long Beach | 9,309 | 140,000 | 15.05 | 17,000 | 121 | 1,820 | 2.04 | 100 |
| 4 | Los Angeles† | 80,960 | 1,100,000 | 13.6 | 45,996 | 109‡ | 1,555 | 1.74 | 97 |
| 5 | Modesto | 1,940 | 17,500 | 9.4 | 1,248 | 195 | 1,760 | 1.97 | 3 |
| 6 | Marysville | 400 | 7,500 | 18.8 | 408 | 149 | 2,790 | 3.12 | 0 |
| 7 | Pasadena | 12,000 | 87,736 | 7.3 | 3,372 | 105 | 770 | 0.86 | 100 |
| 8 | Palo Alto§ | 1,020 | 7,731 | 7.6 | 347 | 123 | 928 | 1.04 | 100 |
| 9 | Redwood City | 1,500 | 8,500 | 5.7 | 190 | 61 | 348 | 0.39 | 100 |
| 10 | Redlands | 6,400 | 16,000 | 2.5 | 1,732 | 296 | 741 | 0.83 | 64 |
| 105 | Riverside | 25,088 | 30,000 | 1.16 | 5,750 | 190 | 220 | 0.25 | 90 |
| 106 | San Bernardino | 4,365 | 33,000 | 7.55 | 7,000 | 212 | 1,600 | 1.79 | 97 |
| 107 | Santa Ana | 5,573 | 33,000 | 5.91 | 7,000 | 212 | 1,254 | 1.41 | 100 |
| 108 | Santa Barbara | 8,051 | 29,600 | 3.68 | 5,000 | 169 | 622 | 0.70 | 93 |
| 109 | Santa Cruz | 5,702 | 15,000 | 2.63 | 4,000 | 266 | 700 | 0.79 | 75 |
| 11 | Stockton | 4,480 | 50,000 | 11.2 | 1,370 | 75 | 840 | 0.94 | 100 |
| 12 | San Jose, Los Gatos, etc. | 20,000 | 80,000 | 4.0 | 2,339 | 80 | 322 | 0.36 | 80 |
| 13 | Sacramento | 8,960 | 70,000 | 7.8 | 7,028 | 274 | 2,140 | 2.4 | 0 |
| 14 | San Diego | 44,800 | 106,047 | 2.4 | 4,894 | 126 | 304 | 0.34 | 100 |
| 15 | San Mateo | 4,800 | 10,500 | 2.2 | 263 | 68 | 152 | 0.17 | 91 |
| 16 | Santa Rosa | 1,339 | | | | | | | |
| 17 | San Francisco | 16,170 | 557,530 | 34.5 | 12,191 | 60 | 2,070 | 2.32 | 100 |
| 18 | Vallejo | 1,725 | 26,641 | 15.4 | 620 | 64 | 980 | 1.10 | |
| | Total | | 3,139,785 | | | 3,541 | | | |
| | Average | | | | | 132 | | | |
| | Total—80 per cent or more metered | | 2,941,785 | | | 2,117 | | | |
| | Average—80 per cent or more metered | | | | | 106 | | | |

*Note:* Data for cities numbered 1 to 18 obtained by correspondence. Data for cities numbered 101 to 109 obtained from Municipal Index 1925 and 1926.

* Service area for cities numbered 1 to 18; land area within political boundary for cities numbered 101 to 109.

† Excluding San Fernando Valley, Elysian and Griffith Parks and shoe string strip.

‡ Average for years 1920–1924.

§ Data for 1922.

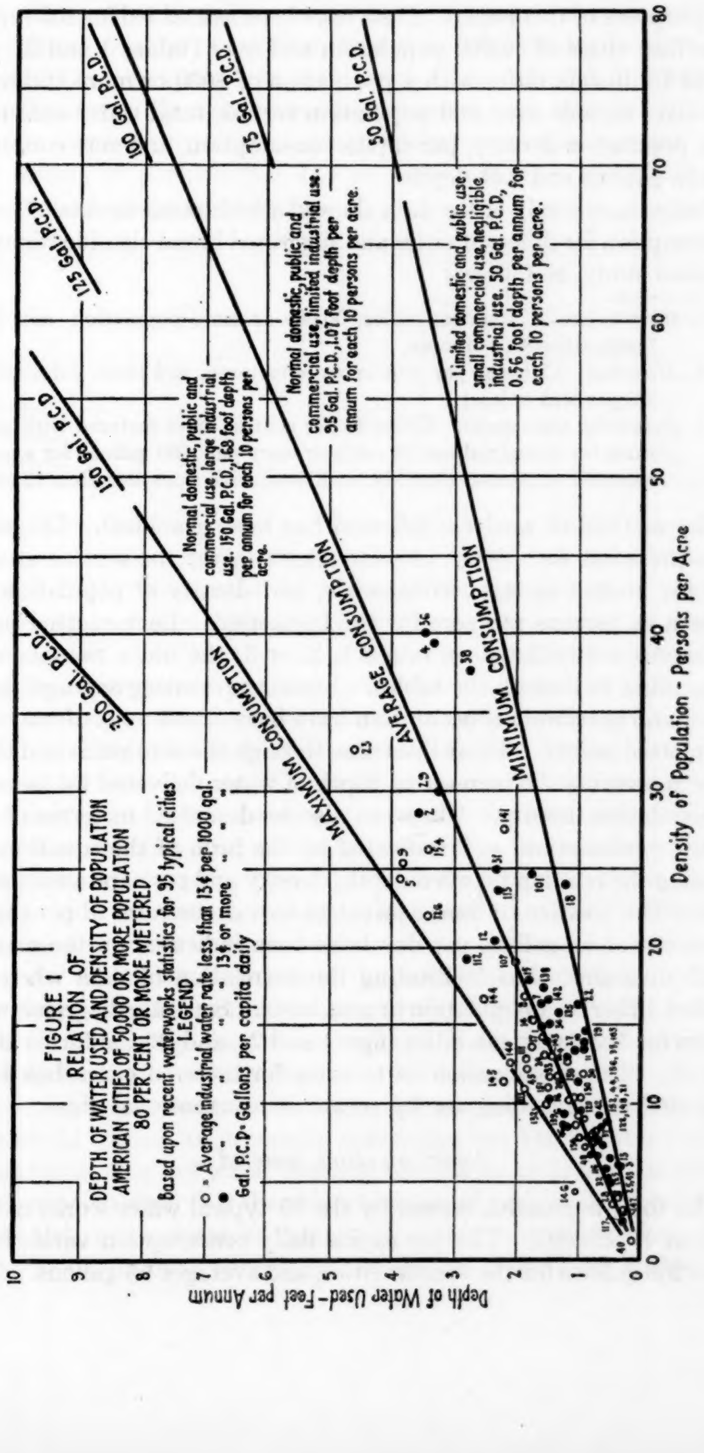


FIGURE 1
RELATION OF
DEPTH OF WATER USED AND DENSITY OF POPULATION
AMERICAN CITIES OF 50,000 OR MORE POPULATION
80 PER CENT OR MORE METERED
Based upon recent waterworks statistics for 95 typical cities
LEGEND
o = Average industrial water rate less than 13¢ per 1000 gal.
● " " " " 13¢ or more
Gal. P.C.D. = Gallons per capita daily
200 Gal. P.C.D.
150 Gal. P.C.D
125 Gal. P.C.D.
100 Gal. P.C.D.
75 Gal. P.C.D.
50 Gal. P.C.D.
MAXIMUM CONSUMPTION
AVERAGE CONSUMPTION
MINIMUM CONSUMPTION
Normal domestic, public and commercial use, large industrial use. 150 Gal. P.C.D., 1.68 foot depth per annum for each 10 persons per acre.
Normal domestic, public and commercial use, limited industrial use. 95 Gal. P.C.D., 1.07 foot depth per annum for each 10 persons per acre.
Limited domestic and public use, small commercial use, negligible industrial use. 50 Gal. P.C.D., 0.56 foot depth per annum for each 10 persons per acre.
Density of Population - Persons per Acre
Depth of Water Used - Feet per Annum

the purposes of this paper. Data have been assembled for 103 typical American cities of 50,000 population and over (tables 1 and 2), and for 26 California cities with a population of 8000 or more (table 3). The data include area and population served, total water consumption, population density, per capita consumption, and acre consumption in gallons and feet depth.

Preliminary study of the data showed a wide range in rate of water consumption for different cities and suggested broad classifications for detailed study, as follows:

1. *Geographical.* American cities, 50,000 or more population, and California cities 8000 or more.
2. *Metering.* Cities 80 per cent or more metered, and those non-metered (25 per cent or less).
3. *Industrial water rates.* Cities 80 per cent or more metered with water rates for industrial use 13 cents or more per 1000 gallons for average amounts consumed monthly, and those with rates less than 13 cents.

The method of analysis followed has been graphical. Diagrams were prepared with depth of water served over the service area in feet per annum as the vertical scale, and density of population expressed as persons per acre for the horizontal. Each plotted point represents a city listed on tables 1, 2, or 3, the index number corresponding to that on the tables. Lines representing average, minimum, and maximum consumption have been drawn to conform with the plotted points. These lines pass through the zero point and their slope represents the increase of depth of water delivered for increase in population density. They can also be described in terms of per capita consumption, as is indicated by the form of the equation expressing the relation between depth, density and per capita consumption. The position of lines equivalent to various rates of per capita consumption in gallons per day have been indicated on the margin of all diagrams, thus facilitating the correlation of data when expressed either on a population or area basis. Separate diagrams were drawn for 103 American cities (figs. 1 and 2), and 26 California cities (fig. 3). The classification as to rates for metered cities has been indicated on each diagram by means of conventional signs.

*American cities, metered*

The total population served by the 95 typical water works in this class is 17,829,091. The per capita daily consumption varies from 46 to 209 gallons for the various cities, and averages 95 gallons. The

range of depth is from 0.1 to 4.58 feet per annum, the latter being for cities of densest population (table 1). The arrangement of the plotted points on figure 1 although somewhat scattered, is definitely limited between the maximum and minimum lines, and clearly indicates the direct proportional relation between depth of water used and density of population. The average, minimum and maximum lines have the following values:

| LINE | RATE OF DEPTH INCREASE PER ANNUM FOR EACH 10 PERSONS PER ACRE | DAILY PER CAPITA CONSUMPTION |
|---|---|---|
| | *feet* | *gallons* |
| Average | 1.07 | 95 |
| Minimum | 0.56 | 50 |
| Maximum | 1.68 | 150 |

The spread of the plotted points on figure 1 is primarily due to the differences in the sum of commercial and industrial use and system losses. This is illustrated by the relative arrangement of plotted points with respect to the lines of minimum, average and maximum consumption. The lowest points, represented by the minimum line (50 gallons per capital per day), comprise the domestic, public and small commercial demand which is the foundation of the water works business. Points located much above this base line indicate that commercial and industrial demand or excessive system loss are appreciable, the extent being indicated by the distance of points above the minimum line, although the average line would probably be the base line for many cities, particularly where garden and lawn irrigation are practiced. It is a well recognized fact that the demand for water for industrial use is very sensitively influenced by the rates charged. An inspection of figure 1 shows that most of the points for cities where the industrial rate exceeds 13 cents per 1000 gallons lie below the average line, while points at which the rate is less than 13 cents lie above. With more detailéd information regarding the relative amounts of water used for various purposes, a diagram of this type would furnish an unusually comprehensive background for the comparative study of water consumption statistics in various cities.

Information regarding the characteristics of various cities, whether residential, commercial or industrial, would also be useful. For example, the normal density of population of built-up residential

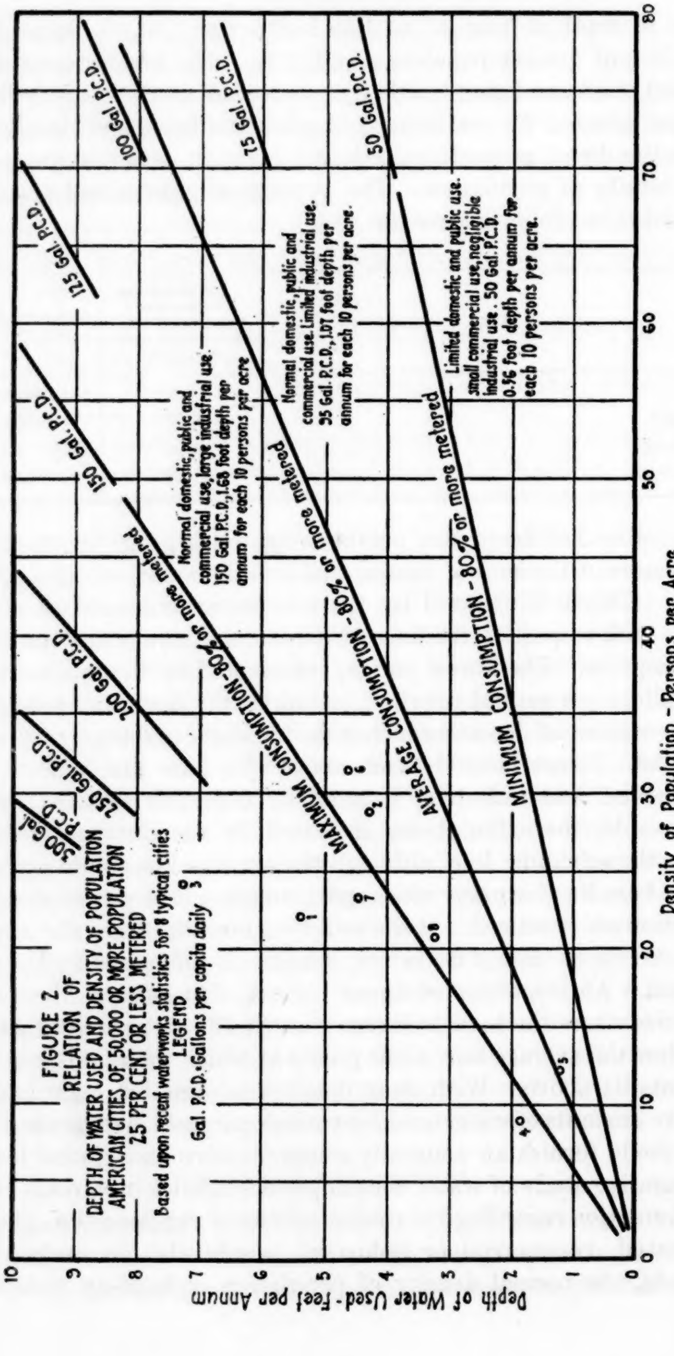


FIGURE 2
RELATION OF
DEPTH OF WATER USED AND DENSITY OF POPULATION
AMERICAN CITIES OF 50,000 OR MORE POPULATION
25 PER CENT OR LESS METERED
Based upon recent waterworks statistics for 8 typical cities
LEGEND
Gal. P.C.D. = Gallons per capita daily
300 Gal. P.C.D.
250 Gal. P.C.D.
200 Gal. P.C.D.
150 Gal. P.C.D.
125 Gal. P.C.D.
100 Gal. P.C.D.
75 Gal. P.C.D.
50 Gal. P.C.D.
MAXIMUM CONSUMPTION - 80% or more metered
AVERAGE CONSUMPTION - 80% or more metered
MINIMUM CONSUMPTION - 80% or more metered
Normal domestic, public and commercial use, large industrial use. 150 Gal. P.C.D., 1.68 foot depth per annum for each 10 persons per acre
Normal domestic, public and commercial use. Limited industrial use. 35 Gal. P.C.D., 1.07 foot depth per annum for each 10 persons per acre.
Limited domestic and public use, small commercial use, negligible industrial use. 50 Gal. P.C.D. 0.56 foot depth per annum for each 10 persons per acre.
Depth of Water Used - Feet per Annum
Density of Population - Persons per Acre
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
80

cities whose population is largely housed in one-family dwellings, is from 8 to 10 persons per acre. This density corresponds on the diagram to a depth of approximately 1 foot per annum for average per capita water consumption. In communities with average water consumption, if the depth of water delivered exceeds 1 foot per annum, it may be concluded either that a considerable portion of the population is living above the first floor level in flats, apartments, hotels or tenement houses, or that the commercial and industrial demand is greater than average. Both factors often act jointly to increase the depth of delivery. Similarly, depths less than 1 foot indicate a partially built-up city or one in which industrial use is small. In a residential city it may also be indicative of the general absence of house gardens.

*American cities, non-metered*

The relative amount of water used by eight American cities of 50,000 or more population, with small per cent of metering (25 per cent or less) is shown by reference to table 2 and figure 2. The total population served is 13,799,000 and the average per capita consumption 167 gallons per day. The latter is 75 per cent greater than the average for cities 80 per cent or more metered (table 1). The points are so scattered that no attempt has been made to draw an average line. The average, minimum and maximum lines from figure 1 have been placed upon figure 2. The latter is instructive, both in its showing of excessive depths of water applied, and of high rates of per capita consumption. Loss and waste as well as low commercial and industrial rates are largely instrumental in producing these charactristics. As experience has often shown, the introduction of extensive metering tends to reduce excessive waste.

*California cities, metered and non-metered*

The determination of depth for California cities was made largely on the basis of service area, since, in many cases, considerable unused land was included within the municipal boundary. There being fewer points to plot, figure 3 includes both metered and non-metered cities.

The total population served in the 26 selected cities is 3,139,785, of which 2,941,785 are in cities 80 per cent or more metered. The average per capita consumption for twenty cities of the latter class is 106 gallons daily, which is 11 per cent greater than for the 95 Ameri-

can cities of 50,000 and over. The maximum is 217 gallons daily or 45 per cent greater. The difference is largely due to the greater use of water for lawns and gardens in the average California city. Average, minimum and maximum lines have been drawn on figure 3 with the following results:

| LINE | RATE OF DEPTH INCREASE PER ANNUM FOR EACH 10 PERSONS PER ACRE | DAILY PER CAPITA CONSUMPTION |
|---|---|---|
| | *feet* | *gallons* |
| Average | 1.19 | 106 |
| Minimum | 0.56 | 50 |
| Maximum | 2.44 | 217 |

The distribution of points is similar to that of figures 1 and 2, and the same general conclusions can be drawn. Rates for water for industrial use have the same influence upon water consumption as in American cities generally. The effect of meters in reducing loss and waste is also apparent. In addition to having a greater rate of water consumption, California cities differ from the average American city in having a relatively small industrial demand. The use of water for irrigation of lawns and gardens appears to be great enough to more than offset the deficiency in industrial demand. This fact points to a material increase in future demand in California cities which may be fortunate enough to have rates low enough to attract industry.

A tabulated summary of all data compiled for American and California cities, based on the curves drawn on figures 1 and 3, has been prepared herewith as tables 4 and 5. These tables set forth the depth of water used in general municipal service in feet per annum for minimum, average and maximum consumption, and for densities of population from 5 to 50 per acre. Their field of application is in estimating future water consumption in self-contained community units. The data do not apply, however, to special services and segregated areas, such as strictly residential, industrial or agricultural. For such, the results of special tests are necessary.

## DEPTH OF WATER IN SPECIAL SERVICES

Water works reports are usually lacking in information regarding the use of water for special purposes, such as domestic, commercial or

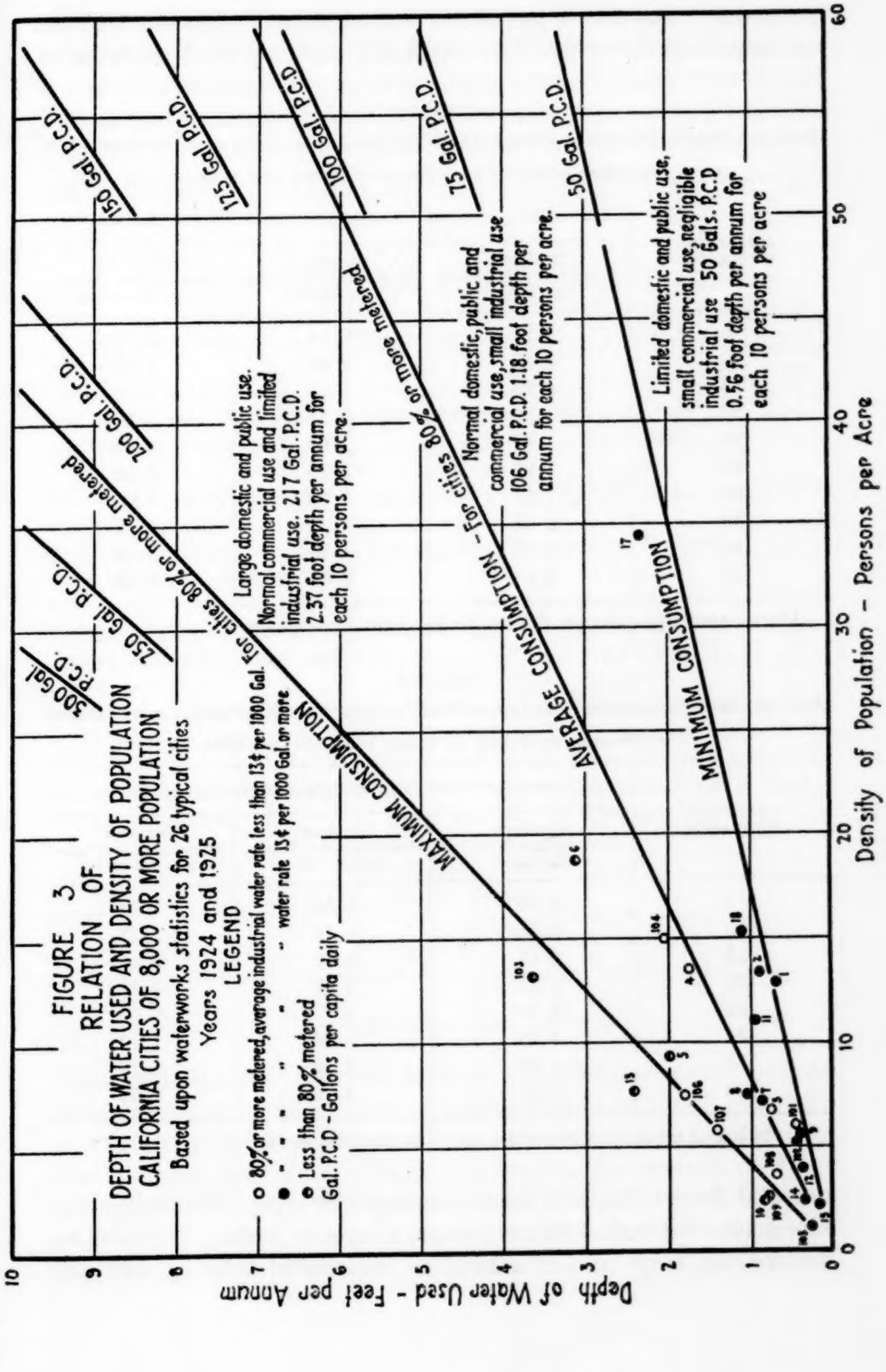


FIGURE 3
RELATION OF
DEPTH OF WATER USED AND DENSITY OF POPULATION
CALIFORNIA CITIES OF 8,000 OR MORE POPULATION
Based upon waterworks statistics for 26 typical cities
Years 1924 and 1925
LEGEND
○ 80% or more metered, average industrial water rate less than 13¢ per 1000 Gal.
● " " " " " water rate 13¢ per 1000 Gal. or more
● Less than 80% metered
Gal. P.C.D - Gallons per capita daily
300 Gal. P.C.D.
250 Gal. P.C.D.
200 Gal. P.C.D.
150 Gal. P.C.D.
125 Gal. P.C.D.
100 Gal. P.C.D.
75 Gal. P.C.D.
50 Gal. P.C.D.
MAXIMUM CONSUMPTION - For cities 80% or more metered
AVERAGE CONSUMPTION - For cities 80% or more metered
MINIMUM CONSUMPTION
Large domestic and public use. Normal commercial use and limited industrial use. 217 Gal. P.C.D. 2.37 foot depth per annum for each 10 persons per acre.
Normal domestic, public and commercial use, small industrial use 106 Gal. P.C.D. 1.18 foot depth per annum for each 10 persons per acre.
Limited domestic and public use, small commercial use, negligible industrial use 50 Gals. P.C.D 0.56 foot depth per annum for each 10 persons per acre
Depth of Water Used - Feet per Annum
Density of Population - Persons per Acre

industrial. The rate of per capita consumption, as determined from statistics in such reports, is a composite made up of all varieties of

TABLE 4

*Average water consumption for typical American cities, 80 per cent or more metered*

Expressed as depth of water over service area

| DENSITY OF POPULATION | DEPTH OF WATER OVER SERVICE AREA—FEET PER ANNUM | | |
|---|---|---|---|
| | Minimum consumption 50 gallons per capita | Average consumption 95 gallons per capita | Maximum consumption 150 gallons per capita |
| 5 | 0.28 | 0.54 | 0.84 |
| 10 | 0.56 | 1.07 | 1.68 |
| 15 | 0.85 | 1.60 | 2.53 |
| 20 | 1.12 | 2.15 | 3.37 |
| 25 | 1.40 | 2.67 | 4.22 |
| 30 | 1.68 | 3.20 | 5.05 |
| 35 | 1.97 | 3.73 | 5.90 |
| 40 | 2.25 | 4.26 | 6.75 |
| 45 | 2.53 | 4.80 | 7.59 |
| 50 | 2.81 | 5.34 | 8.44 |

Data based upon curves drawn for 95 typical cities (fig. 1).

TABLE 5

*Average water consumption for typical California cities 80 per cent or more metered*

Expressed as depth of water over service area

| DENSITY OF POPULATION | DEPTH OF WATER OVER SERVICE AREA—FEET PER ANNUM | | |
|---|---|---|---|
| | Minimum consumption 50 gallons per capita | Average consumption 106 gallons per capita | Maximum consumption 217 gallons per capita |
| 5 | 0.28 | 0.58 | 1.18 |
| 10 | 0.56 | 1.16 | 2.37 |
| 15 | 0.84 | 1.78 | 3.55 |
| 20 | 1.12 | 2.37 | 4.74 |
| 25 | 1.40 | 2.97 | 5.92 |
| 30 | 1.68 | 3.56 | 7.10 |
| 35 | 1.96 | 4.16 | 8.29 |
| 40 | 2.23 | 4.76 | 9.48 |

Data based upon curves drawn for 20 typical cities (fig. 3).

use, and throws but little light upon any one type. The only available source for such data are reports of special tests. With the increased tendency toward zoning, as stimulated both by city and

regional planning programs, more detailed information is coming to be in greater demand. The following specific data for consumption in California cities have been obtained from various sources, and is presented in the hope that it will stimulate the more systematic collection and publication of such information. In addition to other uses, such data would be very valuable in distribution system design.

TABLE 6

*Depth of water in domestic use*

| CHARACTER OF DOMESTIC USE | CITY | AUTHORITY | DEPTH OF WATER USED IN FEET PER ANNUM |
|---|---|---|---|
| First class residential—large improved estates | Los Angeles | Bureau of Water Works and Supply | 2.14 |
| First class residential—large improved estates | Atherton | Charles H. Lee | 2.10 |
| First class residential—large lots with lawns and gardens | Los Angeles | Bureau of Water Works and Supply | 1.90 |
| Second class residential—small lots with lawns and gardens | Los Angeles | Bureau of Water Works and Supply | 1.61 |
| Third class residential—small lots, many with gardens | Los Angeles | Bureau of Water Works and Supply | 1.35 |
| Third class residential—small lots, few gardens | Belvedere, Laguna and San Antonio Twp. adjacent to N. E. Limits City of Los Angeles | Belvedere Water Corporation | 0.68 |

*Domestic use*

Domestic use includes that necessary for human needs, such as drinking, cooking and washing. To this should be added the water used for irrigation of gardens and lawns, where such is necessitated by local climatic conditions. Table 6 indicates the amount of water delivered for this purpose, as shown by various tests. The influence of lawns and gardens in increasing the rate of domestic consumption is quite apparent. First-class residential areas, for example, with

large improved estates consume three times the quantity of water used on areas where the demand is limited to strictly human needs. It is to be noted in using these data that, with the possible exception of the area served by the Belvedere Water Corporation, the data apply to fully built-up districts. The service area as reported for a whole city, on the other hand, would ordinarily include isolated vacant lots and other small non-consuming areas.

*Commercial and industrial use*

The term "commercial use", as generally applied, includes not only the strictly commercial use of water in hotels, stores, office buildings and apartment houses, but also industrial use by manufacturing plants, railroads, sugar refineries, laundries, etc. Commercial use is usually small relative to total consumption, and is constant in amount. Industrial use, however, may be very large in amount and varies with business conditions and the relative cost of water from the public system and from privately developed sources. Considered from the standpoint of area, the two services seldom overlap. With haphazard growth, commercial and industrial plants are seldom to be found mingled, and modern zoning practice tends to emphasize the separation. For purposes of estimating future water requirements, it has been found very useful to have the two services considered separately, and they will be hereafter so considered in this paper.

The amount of water used in commercial service, although a small proportion of total consumption, is large when expressed as depth upon the area to which the water is actually delivered. This is illustrated by a test made by the Bureau of Water Works and Supply of the City of Los Angeles for the consumption in the congested business district bounded as follows:

Hill Street from First to Fifth Street, Fifth Street to Grand Avenue, Grand Avenue to Sixth, Sixth Street to Figueroa, Figueroa Street to Ninth, Ninth Street to Los Angeles, Los Angeles Street to First, and First Street to Hill.

The water delivered to this area of 324 acres in September 1923 was equivalent to a depth of 2.16 feet. As the rate of delivery to this area is practically constant throughout the year, the annual depth may be considered as 24.36 feet. Spread over the whole city service area this amounts to but 0.10 feet in depth, as compared with the total annual depth for all purposes of 1.74 feet.

The amount delivered for industrial purposes in the typical area

of 183 acres bounded by seventh, Sacramento and Alameda Streets, and Los Angeles River, was also measured. This area received during the period July 1, 1923, to June 30, 1924, a depth of 1.67 feet of water. This quantity is very small in comparison with the amount of water consumed in the industrial districts of many eastern manufacturing centers. Inspection of figures 1 and 2 indicate that, for the larger cities, the water used in industrial purposes, if spread over the whole city service area, exceeds 1.50 feet. As industrial plants occupy a minor portion (less than one-fourth) of even the most distinctively industrial cities, it is to be inferred that the annual depth consumed on the area actually devoted to industrial use may be as great as 5 or 6 feet, and may even exceed this figure in the case of special industries using large quantities of water for washing processes. Data are very meagre on this subject, and, with the prospective industrial growth in many western cities, special effort to obtain such information for different types of industry would be well worth while.

### DUTY OF WATER IN IRRIGATION SERVICE

It frequently occurs in western cities that irrigated areas are included within the municipal boundaries. Such lands may either be temporarily used for commercial agriculture in the raising of berries, garden truck, or flowers, or may be more permanently devoted to residential or recreational purposes. Golf courses and public parks and playgrounds may be included within the latter. Often as a city expands it encroaches upon irrigated farm land devoted to the growing of orchards or general crops. The question thus arises in water works practice as to the quantity of water used by such land under irrigation, as compared with the needs of the same land under suburban or urban conditions. The subject of the use of water in irrigation is beyond the scope of this paper, but for comparative purposes certain general data may not be out of order.

The amount of water required in irrigation depends upon many factors, among which may be mentioned climatic conditions, including temperature and precipitation, soils and crops. For lands already under irrigation the stage of economic development of the region and the character of the people are important factors. Recent comprehensive studies made by the State Engineer show that in California the amount of water actually used in various parts of the state for irrigation of general crops varies in depth from 1.14 feet to 3.88 feet per annum, and that a corresponding desirable duty would vary from

1.25 feet to 3.00 feet.[4] These figures are for water delivered to the land, and do not include the large losses in transmission often amounting to as much again as that delivered.

Table 7 compiled from the State Engineer's report gives the aver-

TABLE 7

*Average measured use and duty of water in vicinity of large cities of California*

| CITY | MEASURED USE DEPTH IN FEET | DESIRABLE USE (DUTY) DEPTH IN FEET |
|---|---|---|
| San Diego | 1.26 | 1.25 |
| Los Angeles | 1.62 | 1.75 |
| Bakersfield | 2.24 | 2.00 |
| Fresno | 2.24 | 2.00 |
| Stockton | 2.24 | 2.00 |
| Sacramento | 3.88 | 2.25 |
| Santa Barbara | 2.43 | 1.5 |
| Santa Cruz | 1.42 | 1.5 |
| Monterey | 1.82 | 1.75 |
| San Jose | 1.42 | 1.50 |
| San Francisco | 1.42 | 1.50 |
| East Bay Cities | 1.42 | 1.50 |
| Eureka | 1.52 | 1.25 |

TABLE 8

*Use of water for irrigation in San Fernando Valley, City of Los Angeles, California*

| YEAR | ROTATED CROP ACREAGE, ACRES | NET CROP ACREAGE, ACRES | ROTATED CROP DUTY, DEPTH IN FEET | NET CROP DUTY, DEPTH IN FEET |
|---|---|---|---|---|
| 1919 | 69,000 | | 1.06 | |
| 1920 | 71,000 | | 1.09 | |
| 1921 | 63,300 | 55,000 | 1.20 | 1.38 |
| 1922 | 56,278 | | 1.30 | |
| 1923 | 58,410 | 52,410 | 1.43 | 1.60 |
| 1924 | 60,917 | 51,723 | 1.02 | 1.20 |
| Average | | | 1.18 | 1.39 |

age measured use and desirable duty of water in the vicinity of the larger cities of California.

[4] Irrigation Requirements of California Lands, Bul. No. 6, State of California, Department of Public Works, 1923.

It is to be recognized, however, that the above values represent broad averages and that considerable local variation from them is to be expected. Taking up more detailed data, the irrigation use for general crops in the San Fernando Valley within the boundary of the City of Los Angeles, as served from the City's irrigation system, is reported in table 8 by the Bureau of Water Works and Supply.

More than half the acreage in the San Fernando is planted to crops requiring but little irrigation, such as beans, walnuts, etc. Where a considerable proportion of the crop area is in alfalfa, as in the San Joaquin and Imperial Valleys, greater amounts are used, varying from 2 to 3 feet depth per annum delivered at the land.

The question as to the relative quantity of water which will be required when an irrigated area is annexed to a growing city, with the prospect of the land being subdivided and used for other purposes, is one of growing importance. The past experience at Los Angeles has been that, as irrigated lands are subdivided and become residential in character, with one-family houses surrounded by lawns and gardens, the water requirement remains unchanged or at least does not exceed that for irrigation. The data assembled in this paper confirm this experience and indicate that the same rule would hold for residential cities generally in California, including those in the region of San Francisco Bay. The rule does not hold, however, for cities with population density exceeding 9 or 10 per acre. In such communities the population has begun to live on more than one floor level, apartment houses and flats are in evidence and commercial activities and industries have become established with greater demands upon the water supply.

San Francisco, for example, with a population density of 37.7 persons per acre, uses a depth of water nearly twice the local irrigation use (tables 1 and 7). Long Beach, with a density of 15, uses nearly 25 per cent more water in depth than is used in local irrigation. Even Los Angeles, which, during the past few years has reached a population density greater than 10 per acre, is beginning to exceed the local irrigation requirement. For residential cities in California the rule will probably continue to hold, but as such cities become more metropolitan in character, and industries are established, there will undoubtedly be a change. There are thus very definite limits within which urban water requirements can be considered as acre for acre identical with that for irrigation.

CONCLUSIONS

1. The analysis of water consumption data on the basis of service area is feasible and is more logical for all the varied types of service rendered by a modern water works than is population.

2. The depth of water delivered to the service area in general municipal service varies directly as the density of population. Variation from the average is largely due to the influence of industrial demand or excessive loss and waste. The values for different cities vary from 0.1 to 4.58 feet per annum.

3. In domestic service alone the depth seldom exceeds 2.1 feet per annum, including the irrigation of large beautified estates. For human needs alone the depth is less than 1 foot.

4. Industrial demand requires a maximum of possibly 5 or 6 feet depth per annum, although data are lacking for a definite determination.

5. In commercial districts the demand may run as high as 24 feet per annum.

6. The duty of water in irrigation varies from 1.25 to 4.58 feet per annum.

7. Graphical analysis of water consumption data on the basis of depth of water and density of population offers a method for comparative study which is simple and comprehensive.

8. "Service area acreage" should be added to the items listed in The Manual of Water Works Practice, as the least which a water works system should have (pp. 433–4).

9. The making of special tests of the depth of water delivered in various types of water works service should be encouraged.

# THE USE OF THE DORR CLARIFIER IN WATER TREATMENT[1]

By John D. Fleming[2]

The introduction of the Dorr Clarifier to water treatment is so recent that I may assume some of you are unfamiliar with the apparatus, so I shall give a brief history and description of the mechanism. I would characterize it as a device for the continuous separation of solids from a suspending liquid, the elimination of a large part of the liquid trapped by the settling solids, and the continuous removal from the containing basin or tank, of the solids thus thickened. It was invented and patented in about 1910 by J. B. N. Dorr, a mining engineer, as a device for the dewatering of gold ores undergoing cyanidation. From this metallurgical origin in the West, application of the same principle was made in the East, first to the chemical industries, then to the handling of domestic sewage and trade wastes. Only within the last five years has the Dorr Clarifier entered the field of water treatment, first in water softening, and just now one might say, in preliminary sedimentation of turbid waters, the Kansas City plant being the first designed for this purpose.

Before describing the Dorr Clarifier, I want to comment on its name. A rose may smell as sweet by any other name, but in water treatment a Dorr Clarifier by some other appellation would not give rise to the confusion as to its purpose, which, I believe, often exists in the minds of water works engineers. The names "Thickener," and "Classifier," as applied in the metallurgical industries, are indeed descriptive, but the use of the name "Clarifier" in the sanitary engineering field is not defensible, nor is it descriptive. I cannot refrain from insisting that the name Clarifier is misleading, because one at once associates an influence of the mechanism on the water undergoing treatment and overflowing from the basin, whereas in reality, the influence is exerted on the mud being discharged at the bottom of the basin. Only by reason of the fact that, through the

[1] Presented before the Iowa Section meeting, November 4, 1926.

[2] Assistant Chemical Engineer, Water Department, St. Louis, Mo.

continuous discharge of mud from the basin, the mud line can be held below a predetermined elevation, and thus a maximum detention maintaned continuously, can it be fairly said that the character of the water is affected by the Dorr Clarifier. Since this result is secondary, and the primary interest lies in the disposal of the mud, I would suggest that Dorr "Basin Cleaner," "Sludge Remover" or some other such name would be much more suitable.

The Dorr mechanism in its simplest form consists of a central vertical drive shaft supported by a superstructure, and carrying at its lower end one or more radial arms, on which are mounted a series of parallel rakes. These rakes are set in vertical planes at angles of 45° with the radial arms, the angle being read in the first quadrant from the top aspect. The sweeps of adjacent rakes overlap by a few inches, so that as the mechanism is slowly rotated in clockwise manner, each rake, sweeping over the shallow conical basin bottom, slips the encountered mud towards the center of the basin, the furrows thus swept up coming within the sweeps of the following rakes, which in turn, sweep the mud still closer the center, and so on around, until the innermost rake drops its sweepings into a sharp conical hopper, from which the mud is discharged in a continuous stream, either by gravity or pumping. The interesting thing about this sweeping up of the mud from the floor of the basin is, that, contrary to what might be expected, subsidence is thereby aided, not disturbed. No disturbance is given because the motion of the rakes is extremely slow,—one revolution in three to forty minutes, depending on the size and duty. The aid to subsidence arises by reason of the tumbling action of the rakes on the mud, whereby the watery envelopes over the mud particles are broken, and the water thus freed escapes with added facility given by numerous fine channels in the sludge, these channels likewise being caused by the cutting action of the rakes. Both phases of this theory of thickening are susceptible to laboratory demonstration and proof, but regardless of the theories involved, thickening is a fact, for we have by a laboratory raking apparatus, thickened mud in seventy-two hours to a density not attained in twenty-one days of undisturbed settling.

Clarifiers are made to operate in round or square basins, in units from 9 to 225 feet in diameter, the radial arms of the larger units, e.g., at Kansas City being pulled around by peripheral traction instead of driven from a central shaft. The one being studied by the St. Louis Water Works is an experimental unit, 25 feet in diameter,

shaft driven, and operates in a round tank 7 feet deep. The unit has been loaned us by the Dorr Company, together with accessory tanks and apparatus for supplying chemicals if desired. The equipment was set up at the present Chain of Rocks plant, in a place conveniently located with reference to the raw water supply from the service pumps, sewers, and the chemical laboratory. A 15-foot square tank was placed 8 feet to the north of the clarifier unit, with an eight

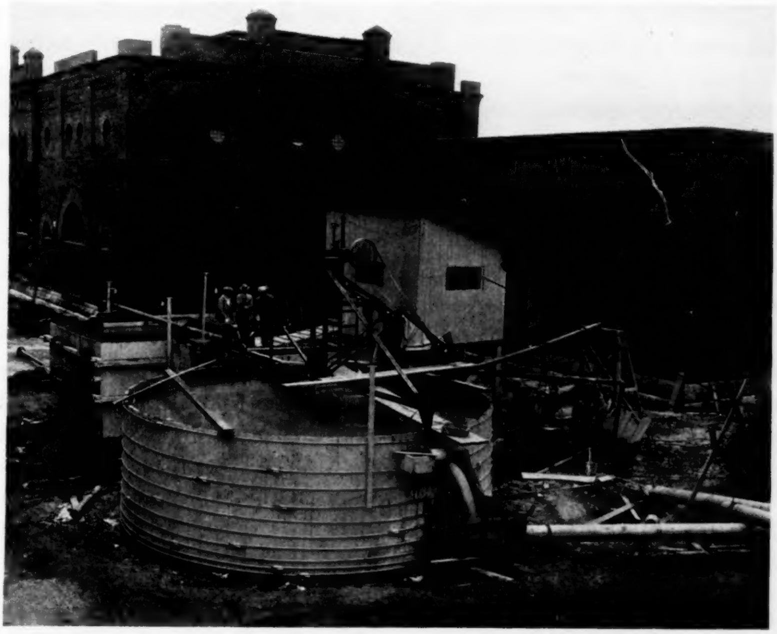


FIG. 1. GENERAL VIEW OF EXPERIMENTAL PLANT AT ST. LOUIS WATER WORKS

channel mixing chamber 120 feet long, between the two. Agitator tanks for supplying milk of lime and iron sulphate solution by gravity feed, were housed just to the east of the mixing chamber. Raw water was supplied through a 6-inch pipe, and measured by direct discharge through bronze orifice plates having sharp edges, the head on the orifice being maintained by a slow overflow from a 3-inch piezometer tube. Arrangements were made for the direct discharge of the raw water into the north side of the square tank, the north end of the mixing chamber, and the filling box of the clarifier. Means of very accurately feeding lime and iron were also provided. The

purpose of this rather elaborate set-up was to study the performance of the clarifier when handling raw water sludge, sludge from softened raw water, and finally, the sludge from water which had been first settled by plain sedimentation, and then softened. It was hoped that, incidentally, some very valuable large scale data would be obtained, corroborative of the writer's laboratory findings, on the chemical savings to be expected from preliminary sedimentation of Mississippi and Missouri river waters.

This was a fairly ambitious program of study, but was doomed to failure of attainment, in part, by the intervention of mother nature. No sooner had operations started, when the suspended solids of the raw water dropped in the course of a week, from 1000 parts per million to 200, and remained there for almost six weeks. The deposition of sludge from such water, handled by any of the three methods of operation outlined above, is so extremely slow, that the study of continuous sludge discharge is rendered practically impossible, as anyone will easily discover by a few simple arithmetic calculations, and a consideration of the natural limitations of models.

Thus thwarted, resort was made to the supplying of foreign or artificial sludge, so to speak. Advantage was taken of the cleaning of our primary settling basin about to be undertaken at this time, and mud from the drained basin was put into the clarifier by means of a jet pump. This sludge, of course, was that from softened raw water, and, while not a fully satisfactory substitute for sludge built up right in the clarifier, it was possible therewith to get some fairly acceptable data on the possibilities of sludge discharge.

To study a sludge approximating that from raw water, we then rapidly discharged the coagulated raw water sludge which had been put into the clarifier, and recirculated it with a jet pump in such a manner as to disturb the settling sufficiently to allow the coagulant and fine clay present to pass out of the tank in the overflow. This was continued until the sludge on dilution showed no evidence of coagulant in its makeup. Furthermore, fine sand from the river bank and some coarse sand from the plant grit chamber was added directly to the tank. A sludge was formed in this way, which, in all probability, was much more difficult to handle than a genuine raw water sludge. The regulation of discharge is accomplished by varying the size of the orifice and adjusting its elevation. This latter variation is obtained by using a riser pipe connected flexibly to the horizontal part of the sludge line at an angle of 45°, so as to give the riser a

swivel action. Measurements and calculations have been made to determine the friction head in the discharge line for orifices varying from $\frac{5}{16}$ to $1\frac{1}{4}$ inch, with discharge rates varying from 730 to 6000 pounds of sludge per hour, the solids ranging between 25 and 58 per cent by weight.

None of the detailed data obtained is to be submitted in this report, but it may be stated in a general way that, by this swivel and orifice method, a continuous gravity discharge of raw and coagulated raw water sludges can be had from the Dorr Clarifier, using a smooth steel pipe, free from all shoulders such as bell joints, valve seats and sharp bends, and provided further, that the rate of discharge be suitable to the density of the sludge. These provisos indicate the necessity of much attention to details of construction, and a rather complete analytical knowledge of the formation, as well as the discharge of the sludge. By careful supervision of this kind, I have every reason to believe that the Dorr "Basin Cleaner," as I choose to call it, will thus continually hold the mud line in a basin to a predetermined elevation, with an actual water loss of less than 0.2 per cent for each 1000 parts per million suspended solids in the feed water.

The study of sludge removal by diaphragm pump is about to be made. It seems quite likely that, by pumping, a very much simpler regulation of flow can be obtained, and the economical handling of very dense sludges, probably 40 to 50 per cent solids, is anticipated.

## CENTRIFUGALLY CAST PIPE[1]

Robert B. Morse:[2] Our district, which covers the suburban areas in Maryland near the District of Columbia boundary, has purchased approximately 90 miles of deLavaud pipe and most of this has been laid already. All sizes of deLavaud pipe, from 6 to 16 inches, have been installed, and we now have a 20-inch line under construction. Up to this time, practically all of the pipe has been laid by our own forces, but we have two large construction contracts, involving the use of deLavaud pipe, going on at present.

Our experience with this kind of pipe has been somewhat similar to that of Mr. S. H. Taylor. No difficulty has been experienced in handling and cutting, except in the case of three pieces of 12-inch pipe, distributed in one street, which cracked while being cut. We have had some trouble, however, with pipe that has split after being laid in line, this taking place in some cases a long time after the main had been placed in service. Most of the early breaks occurred in connection with pipe from several shipments that bore evidence of poor loading or rough treatment in transit; but later mishaps, somewhat less, though disturbingly, frequent, cannot be accounted for so easily. Pipe of 12-inch diameter is the worst offender in our system.

Our men find some difficulty in using fittings with deLavaud pipe. Although the fittings are supposed to be ring-calipered at the foundry, some of their spigot-ends cannot be inserted in the deLavaud bell. The deLavaud spigot, on the other hand, having no bead, has allowed the jointing material (leadite, in our practice) to pass by the braided gasket, in some instances, and enter the fitting at the bell-end. We have eliminated this trouble by using loose unoiled jute for the bells of fittings.

The workmen on our lines like deLavaud pipe much better than sand-cast, on account of its light weight and the facility with which it may be centered. It must be handled with reasonable care, however.

[1] Discussion presented before the Buffalo Convention, June 11, 1926.

[2] Chief Engineer, Washington Surburban Sanitary District, Hyattsville, Md.

We take bids on both sand-cast and deLavaud pipe on the linear foot basis and have found that the delivered cost of the latter has been from 5 to 10 per cent less than of the former.

Charles W. Sherman:[3] In some ways my experience with centrifugally cast pipe is not quite as intimate as that of those who have taken part in the discussion up to the present time. I am Chairman of the Board of Water Commissioners in the town in which I reside, Belmont, Mass., and have not personally handled the pipe like the superintendent who has put it in the ground, and who has to make repairs if any are to be made. I have also been consulting engineer to towns which have laid some of this pipe, and again my experience with it has ended when the pipe was laid. I have had something to do with 10 miles or so of deLavaud pipe up to 14 inches in size, which has gone into the ground, and as much more of 6- to 16-inch which is going into the ground this year.

My experience has been entirely favorable.

My first order was an experimental one. I think I bought fifty lengths of six inch pipe, to see how it would work out, and told the superintendent to use reasonable care, but nevertheless to find out what the pipe was good for. His report was favorable; and since then in my own town, we have bought nothing else, because we found that we could save money and get satisfactory pipe. I have no specific figures, but I am confident it has cost us less to handle this pipe and put it into the ground than for the sand cast pipe. We have not dropped the pipe into the trench as described by some of the previous speakers. We use a tripod derrick, and we have had no breakages. There have been breakages in transportation by rail and by trucks to the job, about the same as with the sand cast pipe.

As for cutting, once the men learned how to do it, we found no particular trouble. Light blows are essential, as was noted by several of the speakers. It is very easy to crack the pipe by striking too heavy blows, and a crack is likely to be a longitudinal crack, spoiling quite a piece of pipe. As to tapping, I have heard objections by some who had no experience with the pipe, that the wall was too thin. We get threads enough, and they are beautiful threads. My superintendent assures me that he can screw a corporation cock in by hand and make a tight joint.

[3] Consulting Engineer, Metcalf and Eddy, Boston, Mass.

Some of the other advantages are worthy of reiteration. We get a pipe slightly larger than the nominal diameter, which means increased carrying capacity. If tuberculation occurs, it may continue for a time before we even get down to the carrying capacity of a new pipe of the nominal size. Experience has been too short to prove it, but I am inclined to believe that the dense iron which goes into this pipe will tuberculate less rapidly than the sand cast pipe. In most of the centrifugal pipe the interior surface is very smooth, more so than the ordinary sand cast pipe, which would mean a better coefficient of carrying capacity when new. In my own experience I have found the interior surface to be somewhat less satisfactory with the larger sizes. The 6-inch pipe was almost as smooth as glass; the 8-inch not quite so good; the 12-inch was not so smooth and the 14-inch was still less smooth. The 16-inch is cement lined, anyway, so we do not know what the interior surface of the iron is like.

D. A. Heffernan:[4] This year for the first time our purchase of cast iron pipe for mains consisted entirely of deLavaud, the pipe being lined with cement. Just previous to leaving home for this convention we had completed a 10-inch line, 2300 feet long. Inasmuch as it was the first time that we had used centrifugally cast pipe, I gave an unusual amount of personal supervision to the work.

In the first place I made certain that the pipe was unloaded carefully. I might mention in passing that we unload all our own pipe and deliver it at or near the jobs on which it is to be used. We did not run up against one length of pipe that was damaged. On all our main work we test the pipe line by water pressure before the pipe is covered. I will admit that I was perhaps a little nervous about the pipe at first, but I can truthfully say that, if ordinary care is given in its handling, there is no danger of the pipe cracking or breaking.

For the information of some who may be considering the use of this pipe I will tell them that, in cutting it, the use of a dog chisel and heavy blows of the hammer are liable to cause damage or, at least, result in a very ragged cut. The hammer and dog chisel may be used with very good success if light blows are struck. I have also cut this pipe with a wheel cutter and had very good success with it.

I understand that there are several cities and towns in my vicinity where cement-lined pipe is being used but where fittings are unlined. My belief is that if a community intends to use cement-lined

[4] Superintendent, Water Department, Milton, Mass.

pipe it should go all the way and use cement-lined fittings. I consider this the best practice because we ran up against the same experience with cement-lined wrought iron pipe which we used in our services. At first, these fittings were unlined and we experienced trouble where the pipes were joined. Later on we began to line all our fittings with lead and have overcome our earlier worries, and, I believe, have now a very long lived service.

I know of two concerns who are equipped to deliver fittings with a cement lining and I am sure they both will give good service.

Mr. Crane (St. Petersburg): We have had experience in putting in 6 to 7 miles of deLavaud pipe, 6 to 8 inches in size. We have had some hardness, some brittleness, but generally it has been along the line spoken of, and I would say that now the city of St. Petersburg has entered a contract for between 60 and 70 miles of this same pipe, and we expect to get as good service in that as in previous lots.

Wm. W. Brush:[5] I should like to inquire whether, in tapping, any of you gentlemen, who have used the pipe, have reduced the maximum size of the tap that you would put in a given sized pipe? Presumably the usual sized tap will satisfactorily go in even the thinnest walled pipe that you have, but have you reduced the maximum sized tap that you would put in any given sized pipe, on account of the thinner wall?

Mr. Haines: We do not make any difference; we use the Muller machine and tap them as they come. We cannot see that it is necessary to make any change in the size of the tap. We get a good thread and a tight joint and everything seems to be satisfactory.

Stephen H. Taylor:[6] We have not changed our practice at all. I think the metal is so much more dense and strong that we get a very much better thread, so there is no reason for making a change.

Robert B. Morse:[2] We have made no change, either.

[5] Deputy Chief Engineer, Department Water Supply, Gas and Electricity, Municipal Building, New York, N. Y.

[6] Superintendent, Water Works, New Bedford, Mass.

William J. Willson:[7] We have not got very much of that pipe, but we have a little over a mile of 6- and 8-inch. I was rather surprised to hear people say that the pipes were tumbled into the ground. Our practice has always been for all kinds of pipes to lower it down with a rope. One speaker said that, in regard to the cutting of pipe, it was liable to crack. Our experience is that it cuts very much better with wheel cutters. We do not cut it with anything else, except if we have to do it in a confined space. In regard to tapping, we use the Muller tapping machine and have not altered our arrangements at all. We find that the thread is a very much better thread. We get better results from it with the deLavaud pipe than we did with the others.

Wm. W. Brush:[5] Do your tappers make about the same progress in tapping, about the same length of time?

William J. Willson:[7] I have timed both cases and there is practically no difference between the two in tapping.

L. VanGilder:[8] I just want to add my testimony to the value of the deLavaud pipe. Two or three years ago we began getting some shipments, carload shipments of 6- and 12-inch pipe. We had a little difficulty at first; the 12-inch pipe came from Birmingham, as I understand, through the representative of the United States Company. The trouble was in annealing, but since they have been annealed, we have had no difficulty with it at all, and this year's requirements for the entire year's contract has been with deLavaud. It has been eminently satisfactory and answering Mr. Brush's question about the size of the pipe, I would say that we have no difficulty in putting in 2-inch screw taps in 4-inch pipe, which would be the maximum size of tap and the minimum size of pipe for our use.

Robert B. Morse:[2] We have found the wheel cutters unnecessary. We used them at first, but our men now use with perfect facility the ordinary cold cutter.

Mr. Fletcher: I think possibly mention should be made of our particular situation. Most of our trenches are dug through

[7] Superintendent, Greenwich Water Company, Greenwich, Conn.
[8] Engineer and Superintendent, Water Department, Atlantic City, N. J.

sand, and the last 2 feet possibly are in a clay bottom. We have one man who handles this pipe, throws it into the pit and it is thrown with the bell end over against the soft sand cushion and rebounds so there is no danger of any breakage. We have not had any breakage with the sand cast pipe. The deLavaud pipe requires two men to lower it down with ropes. That means an extra man in our particular situation. Other situations may be different. The same is true in unloading the pipe from the wagon; they roll the sand cast pipe off and drop it down a considerable distance in new allotments where there is more or less soft cushion and grass. We could not do that with the deLavaud pipe, and it requires another extra man. That is why I made mention of the fact that in our particular situation it requires two more men, and that amounts to more than the difference in the cost of the two pipes. With that careful handling, the deLavaud costs us more money. I am also wondering whether any of you have used it long enough to know whether you have expeienced any trouble with this heavy truck traffic, with the rebound from trucks, etc., transmitted to this pipe, that you all admit breaks more easily than the sand cast, or have you used it under railway tracks where even the sand cast pipe breaks? I have not had any experience, because I have not placed it under railroad tracks, but I have been wondering whether anybody has.

Robert B. Morse:[2] We have probably made a dozen or more railroad crossings with deLavaud pipe, with no trouble at all, and had no apparent trouble under heavy traffic. Our mains are laid with from 4 to 4½ feet of cover, and there has been no breakage at all except in those places I spoke of, which were all in one or two shipments of the pipe. A cover of 6 feet is used under railroads.

Mr. Sayre (Montreal): I would like to bring up one phase of the question, and that is we buy our pipe by weight, based on the standard specifications for Class C pipe. I was wondering how we could buy a lighter pipe and a denser pipe on those specifications in open tender? We have not used any of the lighter pipe for that very reason; we have successfully defended in court claims for pipe breakages based on the fact that our pipe was the standard weight and thickness, and much as we would like to use lighter pipe, we have not been able to have the weight of the specifications behind us to do so. In our specifications we ask these weights, and we do not see

how, if we changed that, and got a lighter pipe, we could avoid getting in trouble as it would not be covered by the standard practice of the specifications.

Stephen H. Taylor:[6] We add to our standard specifications the fact that proposals will also be received for deLavaud centrifugally cast pipe, which takes care of the contract end of it. I should think as far as the legal end of it goes, we have never had any experience along that line, but if we follow the standard and buy pipes that are guaranteed for the pressures we are carrying, I should think we would be on as safe ground as with the sand cast pipe.

A Member: Answering the question of the gentleman from Montreal, our experience is this. Our specification was based fully on Class D, with an invitation for an alternative proposition on deLavaud pipe of equal strength and carrying capacity, and our bids were more favorable from the deLavaud people. As far as railroad claims, perhaps, knowing the standard weight of equivalent pipe in deLavaud, which I am sure the manufacturers would be glad to give, would let us out. For instance, a Class B, 6-inch, weighs 400 pounds and deLavaud weighs wbout 325 pounds for a similar length.

William J. Willson:[7] Prior to my coming to the convention, there was a private development which had used about 9000 feet of 4- and 6-inch deLavaud pipe. This was put in connection with our system. Being a little skeptical about the use of deLavaud pipe, I thought it was a good opportunity to try it out at the expense of some one else. We subjected all that pipe to 310 pounds pressure after it had been laid in the trench. Of the total amount that had been laid, we found nine lengths of pipe that had to be removed, which had probably been fractured in handling either in the shipment or delivery on the job. The reason we did not put any higher test than 310 pounds is because the pressure would not go any higher.

# INVESTIGATIONS OF THE NORTHERN END OF LAKE OKEECHOBEE FOR DEVELOPMENT OF POTABLE WATER SUPPLY[1]

By W. E. Darrow[2]

## PHYSICAL CHARACTERISTICS OF LAKE AND SURROUNDING TERRITORY

When one enters that section of the state of Florida which lies between the hill region of Lake Stearns and the ridge section of the Eastern Coast, especially if one motors across this territory, using State Road No. 8, one is impressed with the fact that the elevations continue practically uniform for miles, changing only by a few feet, and very gradually. This is especially true if one turns south on Parrott Avenue in the City of Okeechobee, and pursues his way over the greatly improved highway to Lake Okeechobee, the shore of which lies approximately three miles south of the center of the town. The average ground elevation of the city is around 31 or 32, Punta Rassa Datum, and the average stage of the lake for the last two years has been about 17.75 to 18.

For the information of those present, who have not traversed the lake, or who have not been over the Conner's Highway, which opened up this large body of water to the acquaintance of many who had not touched the extensive shores of it, the distance from the north end to the south end of the lake is about 60 miles and the east and west dimension is about 45 miles. The greatest depth, as a matter of record from the recent surveys of Captain Graham of the United States Coast and Geodetic Survey is about 17 feet, when the stage is held at the required government level.

## REASONS FOR TURNING TO LAKE OKEECHOBEE FOR WATER SUPPLY

The City of Okeechobee has been for the period of its existence as a city, up until June of this year, under the handicap of using a very hard water, supplied by wells. When equipment was first installed

[1] Presented before the Florida Section meeting, November 18, 1926.

[2] Engineer, Winter Haven, Florida.

for giving the town a supply from the wells, the water was pumped directly into the elevated tank. In 1924, a device for simple aëration, and a concrete settling basin of 50,000 gallons capacity were constructed as additions to the old plant at the well, under the direction of F. E. Lawrence. Before this time and throughout the period of use of the well water, experience in the use of ordinary galvanized pipe for house connections, and ordinary bath room and plumbing fixtures, demonstrated that maintenance costs both to the city and to private property owners were continuing to mount. The average life of galvanized iron pipe connections was about three years. The deteriorating effects on plumbing fixtures caused leakage to be continual, beginning a short time after installation.

As to the quantity of the supply available from the wells, it was found necessary, even before the new plant was well under construction, to drive an additional well, which was comparatively shallow, but gave a good flow equal to twice that of the 800 foot well. However, with this additional amount being pumped to the aëration basin daily, it was necessary to fill and refill the elevated tank so often, that, without constant watchfulness, there was considerable danger of the town going without water. This, by the way, actually did happen several times, due to break down in pumping machinery and other causes which are bound to occur where such a hand to mouth supply exists.

In less than six months after the aëration basin had been put into use, the city authorities decided to have additional investigations made of the water of the lake and, if approved by the electorate, to take the necessary steps to obtain their supply from this source, which was known to be soft.

## COMPARISON OF PHYSICAL, CHEMICAL AND BACTERIOLOGICAL CHARACTERISTICS

Chemical analysis of samples of the up town well water gave results showing a total hardness of about 370 p.p.m.; the bacteriological analysis was very satisfactory.

Samples of the lake water secured during the year of 1925 at varying levels, and in quarter square mile areas, extending one mile in all directions from the approximate point of intake, gave average results, in parts per million, as follows, from the chemical analyses

as determined in the office of the Chief Engineer of the State Board of Health:

| | |
|---|---|
| Total solids | 210 |
| Alkalinity most of which is of a temporary character | 56 |
| Chlorides | 38 |
| Color | 66 |

I do not have the record of separation into items of carbonate and sulphate hardness here for reference, but the average total hardness so far recorded is 49 p.p.m. in the lake at the northern end.

Analyses in May, 1926, showed the following results of water from the intake of the new plant.

| | RESULTS |
|---|---|
| *Physical:* | |
| Odor — Cold | None |
| Odor — Hot | Faintly fishy |
| Turbidity | 5 p.p.m. |
| Color | 92 p.p.m. |
| *Chemical:* | |
| Solids — Total | 152 p.p.m. |
| Solids — Loss on ignition | 93 p.p.m. |
| Solids — Fixed residue | 59 p.p.m. |
| Total hardness | 49 p.p.m. |
| Alkalinity | 48 p.p.m. |
| Total chlorides | 23 p.p.m. |
| Free $CO_2$ | 2.5 p.p.m. |
| Total iron | 0.25 p.p.m. |
| pH | 8.0 |

It will be noted that in both reports on average results that the color is high and it is found that color removal is probably the most important function to perfect in the purification plant.

The bacteriological analyses have shown a very high bacterial count, but none of the B. coli type in any of the samples.

The report of R. E. Rose, State Chemist, in 1924, of analyses of samples taken from an unidentified location in the lake, shows the following results:

Total dissolved solids, 297 p.p.m.

Volatile matter, 81 p.p.m.

Qualitative analysis shows chlorides, and sulphates of sodium, calcium, and magnesium.

Reports a soft water, alkaline in reaction.

States that the water is substantially a rain water, the color of which is affected by vegetable humus.

## EFFECT OF VEGETATION AND FISHING INDUSTRY

The lake, as well as its tributaries are affected, during a large part of the year, by the water hyacinth, which grows in large masses, completely choking arms of the lake, and when dying off year after year, the humus of these plants, as well as of other vegetation, give the waters the heavy proportion of color reported above. There is little opportunity for the vegetable humus to settle deep enough to stay out of reach of the effects of wave action, and thus it is stirred about sufficiently to remain in suspension. In the deeper rivers, for example, the Kissimmee, approximately the same proportion of color has been noted, but it is pointed out that where greater depth is had, the swiftness of the current keeps the humus and finely divided material from settling to a sludge condition at the bottom.

It might be stated that wind action effects a quick stirring of the waters of the lake throughout, it being a comparatively shallow basin as noted above.

Many forms of fish life abound in the lake in certain years more than at other times. The fishing industry, according to the statistics of Leon Latour who has been in the wholesale end of that business for a long time, has been good in the past, but since 1924 there has been a falling off due to various reasons. As far as the industry itself is concerned, the writer believes it is a good thing for the water supply, providing the fishermen or companies operating always obey the state law in regard to disposition of the material from the skinning benches. This regulation requires that all such material shall be buried at certain depths on shore, and not deposited in the lake. It is believed that sufficient activity of the local law enforcement officers, as well as the water works superintendent for the city, is taking place at the northern end of Lake Okeechobee, to obtain the coöperation of the fishermen, thus preventing any undue contamination of the water in the territory under discussion.

The wet season, with its occasional extremely high stages, has its effect not only on the characteristics of the lake water, but also must be taken into account in the design of the structures of a purification plant, as will be noted below. As yet the writer has had no opportunity to investigate the conditions of extreme low water occurring in

some of the dry seasons, and when, from the last eleven years rainfall and lake stage chart, it is noted that extreme low water has reached the elevation of 13.9 we can assume that there has been and is apt to be considerable change in the characteristics of the lake water when considered from the water supply standpoint. The stage of the lake level for the last three years has ranged between 16.9 and 19.0.

Considering the lake as a large impounding reservoir some study is being made of the characteristics of micro-organisms present. There is not, to the knowledge of the writer, any data available, and of course it is necessary, in order that the data be worth something, that investigations along this line extend over a period of years.

## THE WATER PURIFICATION PLANT AND PUMPING STATION CITY OF OKEECHOBEE

The problem of securing suitably located property for the erection of a water purification plant and pumping station for the City of Okeechobee was rendered quite difficult, due to the prevailing prices of lake shore real estate. The property purchased by the city is located approximately 1000 feet west of the northern end of Conner's Highway, and includes a portion of the so-called ridge or rim of the lake basin on which the plant proper is located, in order to get all the advantage possible in the construction of the main drain. The average elevation of the top of this ridge is about 23.5 and taking this into consideration, along with the work that undoubtedly will be accomplished by state and federal coöperation in keeping the lake stage at the required government level, it is believed that the wash water and wastes of the plant will always be taken off without trouble, but anticipating possible setbacks, a reinforced concrete apron was constructed at the outfall of the main drain, and doweled sufficiently to receive the necessary side walls for a future sump, in case the waste drainage might at anytime have to be pumped. This arrangement will also prevent flood waters from rising into the low lift pump pit, in case such a thing could happen.

### *Capacity*

The plant will provide a supply of one million gallons per day of twenty-four hours.

*Structures*

The plant consists of an intake, pumping station, chemical mixing arrangements, coagulation and sedimentation basin, filters, chlorinating plant, filtered water reservoir and high lift pump chambers. All structures are of reinforced concrete, requiring good foundations. Scarcity of suitable filling material prevented the use of paved slopes in constructing water containers, except in the case of the coagulation basin, where considerable hard work was experienced in getting a water tight job.

The intake screens, two in number, are located within a timber pier, approximately $\frac{3}{4}$ of a mile from the shore, and are connected to the intake valve chamber by a 14 inch diameter cast iron pipe line. Ways and means of reducing the cost of constructing the intake were analyzed, but it is believed that the results of the first hurricane, which occurred in August of this year, demonstrated the use of the long pipe line. As a matter of record the blow carried the waters practically clean, exposing the lake bottom, about 200 feet beyond the intake, although the waters receded within an hour.

The pumping station is built of red tapestry brick, the copings of which are precast reinforced concrete. The structure is designed in a manner to save space; to reduce suction heads to the minimum; to give easy and ready access from pumping station main floor to the filter operating floor, and part of the building walls are made common to the side of the pump wells, and to one side of the concrete walls of the settled water conduit and filtered water conduit, which form a multiduct.

On the main floor, are located two high duty pumps, the incoming panel switch for the 2300 volt circuit; three $7\frac{1}{2}$ k.v.a. transformers for furnishing the 220 volt current to the low duty pumps and for lighting the building and works; the indicator recording pressure gauge for the discharge main; the indicator recorder of the venturimeter of the discharge main; the wash water rate controller, implement and storage room, lavatory, and telephone. In the lower level are placed two intake pumps, with starters, the manifold piping from the intake chamber, and the dry feed machine and suction box for introducing the coagulant into the manifold. The high duty pumps consist of one 750 g.p.m. two stage centrifugal pump, driven by a 75 h.p. ball-bearing motor, and one 350 g.p.m. two stage centrifugal pump, driven by a 40 h.p. ball-bearing motor.

The low lift on the intake is operated by two 1000 g.p.m. single stage centrifugal pumps, each actuated by a 15 h.p. ball bearing motor. Pumps and motors were manufactured and furnished by the Fairbanks-Morse Company.

The coagulation basin is designed with sloping sides and three round-the-end baffles, the top dimension being 90 feet by 100 feet and depth 12 feet, with a capacity of 500,000 gallons. Provision for convenient drainage and cleansing of sludge is made through a double shear gate chamber into which are connected three 12 inch concrete troughs built into the bottom of the basin.

The piping and appurtenances in the pipe gallery are reduced to a minimum, only such material being used that will control the influx of settled water and the passage of the effluent through the rate controllers, pipe being used for the introduction of the wash only. The mains for settled water and filtered water, as well as for the main drain, are conduits of a three story multiduct.

Two filters of a nominal capacity of 500,000 gallons daily, each, have been completed, with such a flexible design and layout, that additional plant capacity can be conveniently added in the future, with a minimum of delay and inconvenience to the present plant. The construction of the underdrains not only affords an excellent distribution of the wash water without cross riffles, but forms a definite economy in filter underdrain design. Essentially the system consists of A-1, 2 inch by 8 inch Y.P. timbers placed on edge at fixed spacing of one inch between slats, the spacers being secured by brass screws. However, a detail of the design includes a properly shaped reinforced concrete bottom or invert of the filter.

The filtered water reservoir has a capacity of 750,000 gallons and connects with the filtered water conduit, through a 24 inch sluice gate. It is connected to the three compartments of the pump well, each connection being a 24 inch sluice gate, and can be drained completely through a 12 inch sluice gate connection to the main drain. It can also be cut off from the plant completely, and the filter effluent turned directly to the pump chambers; affording opportunity for inspection or cleaning.

As much storage capacity as the available money would permit has been provided, for a number of reasons, among which is the fact that the city decided to use current from the local power company, with no stand-by in the pumping station, the line furnishing the current being a single, side circuit on a pole line 2½ miles in length and

subjected to heavy wind storms. And again, deeming it wise to provide no cross connection whatever, for bypassing the treatment plant, which fact prevents the use of raw water in the mains, considerable storage was rendered necessary.

All filtered water is sterilized with a Wallace & Tiernan Chlorinator Type M.S.A., the chlorine being applied directly into the filtered water conduit before the effluent reaches the sluice gate outlets.

The cement lined, cast iron force main to the city proper is $2\frac{1}{2}$ miles in length; uptown pressure distribution being effected by a new 250,000 gallons elevated tank now under construction, and by the old 50,000 gallon tank in the northwestern section of the town.

Valves and sluice gates were furnished by the Michigan Valve and Foundry Company of Detroit, R. D. Wood & Co., Philadelphia, and the Columbian Iron Works, Chattanooga.

Rate controllers were furnished by the Simplex Valve & Meter Co., and the venturi meter by the Builders Iron Foundry.

Pipe and special castings were furnished by the American Cast Iron Pipe Company.

Intake pipe was furnished by the Central Foundry Co., N. Y.

The Dry Feed Apparatus was furnished by the F. B. Leopold Co., Inc., Pittsburgh.

The Bowyer Company of Okeechobee was the contractor for construction of the plant and general installation.

R. M. Mitchum & Co. of Augusta, Ga., laid the pipe lines and completed the lake intake.

# REPORT OF METROPOLITAN WATER BOARD OF LONDON

## TWENTIETH ANNUAL REPORT ON THE RESULTS OF THE CHEMICAL AND BACTERIOLOGICAL EXAMINATION OF THE LONDON WATERS FOR THE TWELVE MONTHS ENDED MARCH 31, 1926, BY SIR ALEXANDER HOUSTON

An Abstract by Norman J. Howard[1]

The year 1926 marked the twentieth anniversay of Sir Alexander Houston's appointment as Director of Water Examination for the Metropolitan Water Board of London, England, and in his twentieth annual report he has included a historical review of the New River, which supplies a large portion of the Metropolitan area. The history of this supply is vividly portrayed on some 38 pages, and takes us back to the year 1611 about which time the New River scheme was being promoted by Sir Hugh Middleton. The article not only is of great historic interest, but also illustrates the enormous importance of intelligent foresight in providing for a future water supply: the breezy literary style is an additional attraction. The fact is of interest that the price of an original "Adventurers share," amounted to about $1680 in 1610, while in 1898, some 278 years later, part of a share was sold in London for $642,000.

*Chlorination of River Thames water.* Instead of being stored in the Staines Reservoirs, water is being pre-chlorinated which not only partially purifies it, but also saves the cost of pumping into the reservoirs, estimated at $52,300 for 24,540 million gallons treated. After treatment 48 per cent of samples were negative for B. coli in 100 cc. Average dose of chlorine was 0.4 part per million and cost was 19.6 cents per million imperial gallons.

*Chlorination of New River supply.* This supply was treated with chlorine for sterilisation and with potassium permanganate and ammonium chloride for taste prevention. Chlorine was applied on 137 days, permanganate on 103, and ammonium chloride on 40 days.

[1] Bacteriologist in Charge, Filtration Plant Laboratory, Centre Island, Toronto, Can.

Total cost of chemicals per million gallons of water treated amounted to 41 cents. Average dose of chlorine was 0.283 part; of permanganate, 0.205 part; and of ammonium chloride, 0.747 part per million. Taste was reported in the New River supply on two days; in comment on which the author states "The set-back was of the slightest, the matter being remedied almost at once, but its occurrence only shows the necessity of skilled supervision, continuously exercised, and the importance of narrowly watching changes in weather and in the quality of the water being treated." As regards purification effected, results are slightly in favor of the chlorine and ammonia combination.

*Leptospiras (Leptospirae) in water.* An entirely new study which seemingly may be of great importance is mentioned for the first time in this report. Section 111 deals with the possibility of spirochaetal jaundice being in part water borne. In 1922 a seaman fell into the Thames and was nearly drowned. He swallowed a lot of impure water and within a few days developed a typical attack of spirochaetal jaundice, and the leptospira which presumably caused the disease was found in guinea-pigs inoculated with the patient's blood. This type of infection has been largely associated with wet conditions, e.g., wet trenches in France, paddy fields in Japan, and wet mines in Scotland. Most authorities, however, consider that the real carriers of the disease are rats. Recent work by Okell and his colleagues would suggest that dogs must also be considered as potential, though probably not important, sources of danger. Details of the recovery of leptospirae from slime in the damp roof of a tunnel following an outbreak of spirochaetal jaundice are given. A culture of leptospirae was recovered from the Deptford Garden Well which is part of the London supply and a water of remarkable purity. In discussing this, Houston states that "it may be said that the result confirms Buchanan's experience that leptospirae, living apparently under saprophytic conditions, may on occasion, possess pathogenic properties, so far as the lower animals are concerned." Later he states "A water might readily be contaminated specifically by a leptospiral rat and so be in a condition to produce the disease (it should, however, be remembered that although saprophytic leptospirae must be often swallowed, they are apparently absent from normal human feces) and, further, such a water might possibly in passing over slimy materials or other suitable pabulum allow of pathogenic leptospirae establishing themselves in the slime and

multiplying there. Such a slime would presumably have specific pathogenic properties, and it is impossible to say how long this potentially infective property would persist. The writer is here assuming (on the basis of Buchanan's experience) that pathogenic as well as saprophytic leptospirae can multiply in slime. Although the writer is inclined to think that the rat poisons water and slime, it is possible that Buchanan would reverse the process and say that water and slime may, independently of any mammalian infection, be the means of conveying the disease to rats. Recent experiences seem to point at all events to the desirability of avoiding "dead-ends" in a water system, of taking water for drinking purposes direct from the main, and of having cisterns kept clean, covered, and inaccessible to rat pollutions. Old defective "washers" may not improbably be a nidus for leptospirae, so a dripping tap should, apart from the question of waste, carry a warning of possible danger. At least this would be the view of those who attach importance to the multiplication of these organisms. All will agree on the desirability of an intensive campaign against rats and generally on the avoidance of damp filthy places and impure surroundings.

As regards water supply, the writer is in a quandary; for, as will presently be shown, leptospirae are present in filtered waters as well as in the raw sources of supply, and even deep wells come within the same category. Moreover, since leptospirae can pass through Berkefeld filters, which hold back all the ordinary bacteria, sand filters would seem to be useless in this connection. It is not improbable that not all the leptospirae met with in filtered waters are derived directly from the leptospirae in the raw waters. It is impossible to imagine the complete absence of slimy conditions in connection with a system of water supply (storage reservoirs, filters, underdrains, filter wells, service reservoirs, mains, etc.). It is quite probable that at many points leptospirae may be in course of multiplication and detachment. If water leptospirae are to be feared, it is not perhaps these that are objectionable, but rather those in the impure water antecedent to the purification processes which may have been derived from dangerous sources of contamination. Fortunately, leptospirae are easily killed by means of chlorine, and the dose required is less than is commonly used in connection with chlorination processes. Although the writer does not consider (apart from the puzzling Garden Well result) that the leptospirae in pure and well-purified waters are of much, if any, significance, others may hold contrary views, and to

these chlorination must have an irresistible appeal. The subject presents endless fields for future research, is of immense interest, and is agreeably novel, but so far as Londoners are concerned the writer feels that there are no grounds for anxiety.

*Search for Leptospirae in water.* Hindle's method was used for isolation purposes. Consists of placing 20 cc. of water in sterile petri dish to which is added small amount of human feces and after mixing thoroughly incubate at 25° to 28°C. for about ten to twelve days. A loopful of the mixture is examined under magnification of 1000 diameters and the leptospirae have the appearance of gyrating streptococci. The ends have a hook-like appearance; the movement is axial and stationary rather than progressive in character. Frequently towards the ends a characteristic bulging rotary movement occurs giving a sort of halo-like effect. Morphologically these saprophytic leptospirae are apparently indistinguishable from Leptospira icterohaemorrhagiae, the cause of spirochaetal jaundice, or Weil's disease. If results are negative, specimen should be examined daily up to twenty days. A series of experiments indicated that normal feces do not contain the leptospirae but furnish one of the best mediums for cultivation. A large number of tests were made on the London waters for the presence of leptospirae, which were recovered from several sources including raw water, filtered water and numerous well supplies. With one exception all of the cultures were found to be non-pathogenic. The one positive specimen previously mentioned as occurring in the Deptford Well resulted in the chlorination of the supply. In this case super- and de-chlorination had to be practised on account of the susceptibility of this particular water to taste. There was no evidence of sickness among the consumers of this supply and the chlorination was only undertaken as a precautionary measure. Houston states "There is no evidence, so far as the writer knows, to show that London water consumers are suffering from leptospiral infections of water origin, although millions of leptospirae must be ingested daily. These facts should be borne in mind in judging other supplies. The writer foresees the possibility of cases of Weil's disease occurring, and in searching for the cause. Water is being unjustly blamed, owing to the presence of harmless leptospirae. It is not suggested that water is incapable of carrying infection. Waters contaminated with the discharges of animals suffering from epidemic jaundice would presumably be potentially, if not actually, a serious source of danger. The impression sought to be conveyed is

that until we can distinguish between saprophytic and pathogenic leptospirae the greatest caution should be exercised in forming conclusions."

*Chemical and bacteriological figures relative to pre-filtration waters* are given. Exhaustive figures are included on operation of primary rapid sand filters which were built at Barn Elms, works which have shown that with primary filtration, the slow sand rate can with advantage be increased to approximately three times the normal figure. The average rate of filtration of the primary filters was 140.4 million gallons per acre per day while the percentage of wash water was 3. Sections 6, 7, and 8 deal with *meteorological notes, suspended solids in Thames River water,* and *miscellaneous* topics. In the last named section, the subject of iodine, goitre, and water supply is discussed. Reference is made to the Hunterian lecture delivered in London by Sir James Berry on "Some clinical aspects of simple goitre with remarks on its causation" in which he states: "I may refer to an excellent paper on the subject by Dr. James Wheatley, M.O.H., for Shropshire, who gives the preference to the iodization of salt, and to another by Sir A. C. Houston. It is to be regretted that both these writers appear to fully accept the lack of iodine theory. There is at least some evidence that iodine poisoning may occur from the indiscriminate administration of iodine." Houston in replying, discusses the subject and refers to his comment contained in his nineteenth annual report which stated in part: "Although it seems reasonably likely, if not certain, that the wastage is due primarily to a deficiency of iodine in liquid or solid foodstuffs and accessories, it may possibly be true that the gland in some way conserves its store, provided no toxic factor is introduced to upset the equilibrium of its normal working. That the artificial exhibition of iodine has been shown to be a prophylactic measure of value does not necessarily prove that the essential cause of thyrodism is solely due to a deficiency or absence of iodine in the diet. It may only mean that when certain mysterious states of toxicity exist, the only way to prevent the sustained loss of iodine is to counteract the loss by sustained ingestion. Further, we cannot deny that in certain hypersusceptible persons iodine would seem to be actually contraindicated. Nor must it be forgotten that some authorities dispute the iodine theory, and hold that other hypotheses of goitre causation (e.g., fatigue) should be explored before coming to a decision, and others seemingly go even further, and dispute altogether that definitely

beneficial results have resulted from the exhibition of iodine." Berry's conclusions as to the causation of goitre are as follows:

1. Simple endemic goitre is not a hypertrophy, but essentially a degeneration of the thyroid gland. The gland is not over-active but under active.

2. Whatever may be the connection between iodine and the thyroid gland there is no reason for believing that a lack of iodine has anything to do with the causation of endemic goitre, as found in the human subject.

3. It is quite certain that, at least in the vast majority of cases, the disease is produced through the agency of drinking water.

4. There is much evidence that practically all waters which produce goitre contain frequently, although not necessarily at all times and seasons, mineral matter in suspension, usually in an extremely fine state of division.

5. There is also a good deal of evidence that this mineral matter is generally of a calcareous nature.

6. Organic matter in suspension, although capable apparently of causing a hyperplasia of the gland, at least in animals, has not proved to be the cause of endemic goitre as seen in man.

Berry's paper is supported with hard facts. In one instance he brings forward the remarkable case of a school in North India where over 80 per cent of the children were affected with goitre until a new, and as it proved an iodine-free, water supply was introduced, when the incidence fell to 2.2 per cent and this apparently without alteration in the food supply.

Sir Alexander Houston in discussing Berry's paper wonders whether the mineral matter in suspension may not be merely an accompanying factor and not the "causa causans" of the disease, or, alternatively, whether the calcareous mineral matter in suspension in water produced by the operations of Nature may not be different in some way from artificially produced precipitates. On the subject in general he has an open mind and states that "If lack of iodine is the cause, should waters containing little or no iodine be medicinally treated, or should the iodine be administered in some other way, e.g., as iodised salt. If turbidity is the root of the trouble there should be no difficulty in removing it by filtration, although in certain cases preliminary coagulation by means of sulphate of alumina is indicated. If, however, potential turbidity has also to be considered as in the case of hard chalky waters, the position is more difficult, calling for softening processes, and if the lime, or lime and soda, process is adopted, the removal of the last traces of lime by filtration, or by redissolving the lime by means of carbonic acid."

The conclusions of Dr. James Wheatley are given in full. He

claims that shortage of iodine is the prime factor in the causation of goitre. This shortage is not brought about entirely by a low intake, but is partly due to factors interfering with absorption and utilisation and to other factors increasing the demand. He advocated the addition of iodine to table salt as the most satisfactory method for meeting the deficiency, and deprecated other methods of application.

Other subjects touched upon in section 8 are swimming baths, sterilisation of new mains, decline of typhoid fever, resistance to filtration and microscopical appearance of the pre-filtration waters. A long series of chlorine and ammonia experiments on the treatment and prevention of taste are included.

*Ammonia was added for prevention of taste.* It is generally concluded that ammonia slows up the immediate effect of sterilisation following the application of ammonia plus chlorine, but has potential sterilising properties provided a sufficient contact period is given. The combination is an effective remedy for the prevention of taste in some sources of supply. Results are tabulated in three columns, A, B, and C. The figures in A refer to treatment with different quantities of dichloramine (mixture of ammonia and chlorine); in B, to treatment with ammonia plus chlorine; and in C, to treatment with chlorine alone. In dealing with the raw River Thames water, the relative advantages and disadvantages of the treatments were as follows:

| *Advantages* | *Disadvantages* |
|---|---|
| A. Presumably no taste. | More chlorine required than B or C, but unlike B, only traces of ammonia. |
| B. Presumably no taste. Less chlorine required than in A or C. | Much more ammonia required than in the case of A. |
| C. No ammonia needed. | Potential taste troubles. More chlorine needed than in the case of B, but less as compared with A. |

Ammonia was shown to be an excellent taste preventer in the case of chlorinated waters, but to possess little value as a taste remover. The ammonia was added first (doses usually 0.1 to 0.2 per million) and then the chlorine to the whole volume of water treated. The method of Harold, in which the ammonia and chlorine are added simultaneously to a minor volume of water produces a more intense

reaction resulting in the production of a dichloramine compound. The proportions of the two chemicals are 1 of chlorine to 0.1 of ammonia (as N). Ammonia seemed to behave differently in the case of well waters, as compared with river waters. Super- and dechlorination were completely successful in sterilising the water without the production of taste, even after 1 in 1000 millions of carbolic acid had been added to the well water. For several years past, the Director of the London Water Laboratories has yearly introduced entirely new researches into his reports, and the 1926 report will be found to include new and highly scientific facts.

# MORE WATER FOR NEW YORK CITY[1]

## A Review

By George L. Hall[2]

A resolution of the Board of Estimate and Apportionment of June 17, 1921, requested that the Board of Water Supply "undertake studies to ascertain the most desirable and best sources for an additional supply of water for the City of New York and the manner in which the supply can best be delivered to the several boroughs of the City, . . . ." Reports were submitted by the Board of Water Supply under dates of January 23, 1922, December 18, 1923, and December 30, 1924, for additional pipe conduits and another tunnel for conveying water to the boroughs of Brooklyn, Queens and Richmond. The first two reports were approved by the Board of Estimate and Apportionment and the work authorized is practically completed. Action on the report of December 30, 1924, recommending the construction of an additional delivery tunnel is still pending.

Regarding an additional supply of water to meet the future demands of the City, the Board of Water Supply recommends the development of streams east of the Hudson River by the construction of a series of reservoirs extending from the present Croton reservoir almost to Troy, which will increase the safe yield of the City's sources of supply by 434 m.g.d. The aqueduct from these additional sources will pass through the Croton watershed so it will be possible to divert 121 m.g.d. from that area to the higher level of the Kensico reservoir. The estimated cost of the developments recommended is $347,934,000, not including the new delivery tunnel recommended on December 30, 1924, at a cost of $67,249,000. Regardless of the proposed additional water supply this tunnel is vitally essential to the safety and sufficiency of the City's water supply and its construction should be authorized at the earliest possible time.

Consideration was given to the Housatonic and Delaware Rivers as possible sources of supply. The former lies almost entirely within

[1] Report of Board of Water Supply to the Board of Estimate and Apportionment on New Sources of Water Supply for New York City, October 9, 1926.

[2] Division Engineer, Maryland State Department of Health, Baltimore, Md.

Connecticut. The Delaware, however, is interstate as between New York, New Jersey and Pennsylvania. The commissioners appointed early in 1923, to draw up a compact defining the rights of each state in the Delaware River, successfully concluded their deliberations on January 24, 1925. This compact was adopted by New York and signed by the governor on March 18, 1925. Pennsylvania has not yet approved, while in New Jersey further progress could not be made until the legislature in July, 1926, authorized a new commission for continuing negotiations. It is believed that further conferences will be held, but the outcome cannot be predicted. It is therefore concluded that it is not advisable to wait further for reaching an agreement with the other states involved, since the needs of New York City cannot be delayed too long, as the present supplies will hardly serve until 1935 and the supply recommended cannot be made available in less than ten years.

The recommendations of the Board of Water Supply are based on a report of Thaddeus Merriman, Chief Engineer, and endorsed by J. Waldo Smith, John R. Freeman and Wm. H. Burr, Consulting Engineers.

During the past nine years, Mr. Merriman points out, the water consumption in Greater New York has increased at an average rate of over 31 m.g.d. In 1925 the average consumption was 847 m.g.d. whereas the total safe yield of all sources is 1100 m.g.d. The available margin—253 m.g.d.—will meet the requirements for about eight years. New and additional sources must be made available before 1935. Compared with other large cities in the country the per capita use of water in New York is conservative as the tabulation below shows:

| CITY | AVERAGE DAILY PER CAPITA USE—1925 | PER CENT OF SERVICES METERED |
|---|---|---|
| | *gallons* | |
| New York | 139 | 26.0 |
| Chicago | 296 | 11.7 |
| Philadelphia | 165 | 33.0 |
| Detroit | 140 | 99.1 |
| Cleveland | 127 | 100.0 |
| St. Louis | 140 | 7.7 |
| Boston | 115 | 100.0 |
| Baltimore | 127 | 14.0 |
| Los Angeles | 119 | 99.0 |
| Buffalo | 208 | 16.2 |

The per capita use of water is reasonable, in spite of the relatively small percentage of metered services and when it is considered that no account has been taken of the transients and commuters who daily use city water. Under most favorable conditions ten years will be necessary to build a new supply system and place it in service, so that every effort must be made to obtain the authorization to proceed with the work as early as possible.

Mr. Merriman investigated and studied all possible sources of supply within a distance of 150 miles. The nearest sources available are the east side tributaries of the Hudson River in Dutchess, Columbia and Rensselaer counties. The line of the proposed aqueduct crosses the Croton watershed. The plan includes the diversion into this aqueduct of a portion of these waters by gravity into the higher Kensico reservoir, thus making possible a saving on the cost of pumping Croton water. The capacity of the aqueduct at Kinderhook Creek will be about 150 m.g.d. to be increased immediately above the Kensico reservoir to about 600 m.g.d. Between this reservoir and Hill View reservoir it is proposed to provide an aqueduct with a capacity of 750 m.g.d. "to provide for transporting the maximum draft during periods of peak consumption." Delivery of water from the proposed developments into the City would be through a deep pressure tunnel recommended in December, 1924, which has a diameter of 17½ feet and is 20.2 miles long. This tunnel will deliver, as well as the water of the new and additional sources, a portion of the Catskill water. It will also serve as a second delivery artery whereby Catskill water, constituting five-eighths of the total supply of the City, may be fed into the distribution system. The present delivery tunnel has been in continuous use since 1915. Any interruption in its service will seriously interfere with the City's water supply. The urgency of providing the second tunnel is emphasized.

The plan presented by Mr. Merriman provides for progressive development which will spread the construction costs over a period of 15 years, to be carried out in three stages: (1) The construction of the new delivery tunnel; (2) the aqueducts from Hill View to Kensico reservoir and from Kensico reservoir to the Croton watershed, the reservoir on the East Branch of the Croton River, the aqueduct from the Croton watershed to Silvernails and the reservoirs on the Fishkill and Wappinger and Rocliff Jansen; (3) the aqueducts from Silvernails to Kinderhook Creek and the reservoirs on the Kinderhook, Taghkanic, Stony, Kline and Claverack.

With the completion of this plan the total safe yield of all the available supplies will be 1534 m.g.d., sufficient for the needs of the City until about 1947. The construction program spread over a period of about fifteen years provides for varying annual expenditures of from $2,000,000 the first year, increasing to $50,000,000 the fifth year, then diminishing during the remainder of the construction period.

# THE BIOLOGICAL CONTROL OF IMPOUNDING RESERVOIRS[1]

By Carl Wilson[2]

Whether he anticipates it or not, the engineer who constructs an impounding reservoir for domestic supply is confronted with a problem, or rather, an unending variety of problems, in economic biology. The idea that he is dealing only with engineering structures and a chemical called in common language "water," was shattered years ago, but it is only recently that the water works superintendent seriously attacked the living causes of his troubles on the one hand, or encouraged his aquatic friends on the other. Rarely does a water consumer have any conception of the important part which living organisms play in the quality and safety of the water which he uses so freely. He has a vague, and often erroneous, idea that running water purifies itself, and he is aware that disease may be caused by polluted water, but he is not likely to realize that both effects are due to living things. The observing housewife, whose kitchen tap brings her water which has passed through one or more large reservoirs, may have noticed that the water is softer at the end of summer than it was in spring, but she would never guess that this difference is due to the untiring activities of microscopic plants. The water works engineer who is troubled with evil smelling and tasting water, or who is tormented by hordes of insects in his lakes, knows only too well how important is a knowledge of biology.

In our semi-arid climate, where we are compelled to store immense volumes of water for long periods, and where we have the maximum amount of sunshine, with accompanying high water temperatures, biological problems are not only more varied than in the East, but also more intense and trying. Even the stratification of water in a large storage reservoir, due to temperature differences between the top and bottom waters, is more pronounced here, because reservoirs often receive no influx of new water for months at a time. All sum-

[1] Presented before the California Section meeting, October 28, 1926.

[2] Director of Biological Laboratory, Bureau of Water Works and Supply, Los Angeles, Calif.

mer long and far toward winter, the surface layer of water will be enough warmer than the rest to prevent mixing with water lower down unless wind and wave action should be unusually effective. As a result of this condition, bacterial activity on the organic matter present in the water and in the bottom ooze, quickly absorbs all the free dissolved oxygen, and further bacterial activity must necessarily be of an anaerobic type, with the inevitable production of foul smelling decomposition products which are characteristic of stagnant water. Generally hydrogen sulphide is one of these products. We are told that the thermocline, or line of separation between the deeper, colder, stagnant water, and the upper, warmer, layer of aerated water, lies at a depth of 30 to 35 feet, but in most of our Southern California reservoirs it is likely to be much nearer the top, while in at least one lake with which the writer is familiar it is frequently only ten feet below the surface.

Since the production of objectionable odors in this case is wholly the result of living organisms, the solution of the problem must be a biological one. The answer is, furnish enough oxygen to make anaerobic activity impossible, as bacterial by-products produced in the presence of sufficient oxygen are relatively inoffensive. Complete control of this condition has been obtained in the Lower Franklin Reservoir, on the Los Angeles aqueduct system, by introducing the inflowing water through a pipe lying on the bottom of the lake, and extending from the upper end to within a short distance from the outlet tower. About every 100 feet along this pipe 4-inch openings are provided which shoot jets of water upward, and these jets not only bring to the bottom of the lake a supply of water which is saturated with oxygen, but they also keep the entire body of water in a constant state of circulation. Stagnation never occurs in this lake, and water from the bottom is always as sweet as that at the top.

Lower Franklin reservoir is about a mile long, very narrow, and some 70 feet deep at the dam. Because of its shape, this method of providing circulation is especially effective. The same procedure in Stone Canyon reservoir, which reaches a depth of nearly 200 feet at maximum, is successful, but not to the same degree as at Franklin, due to the greater width and the presence of two large arms which cannot be reached by the pipe system as installed.

Plankton growths in reservoirs afford an outstanding example of the need for control measures, and the methods adopted for their

repression are familiar to water works men, as they are almost universally practiced upon open reservoirs. Sometimes, however, algae may be useful, and the destruction of such a growth is not always advisable. On the Los Angeles system we have a reservoir covering an area of about 100 acres, with a maximum depth of 45 feet, and inpounding 700,000,000 gallons, which illustrates the point. Three years ago this lake was drawn down to a small pond of about five acres extent, in order to make some changes in the outlet, and the exposed bottom ooze gave off sufficient odor to cause complaints from some of the nearby residents. To satisfy these people the lake bottom was plowed over and fresh, clean earth turned over the ooze, making virtually a new bottom for the reservoir. Following this, the steep sides, which were subject to storm wash, were oiled and rolled with a view to prevent cutting. When the lake was filled there was no vegetation of any kind below the flowline, and the incoming water was all filtered. Black bass, blue perch, and carp stocked the lake, and multiplied rapidly. Here was a clear case of unbalanced biological conditions—all animal life. Naturally enough, plankton growths appeared, and they were held in check by the usual copper treatments, but in spite of our best efforts the water became stagnant and had to be withdrawn from service. Briefly, the oxygen demand of the fish population (necessary to keep down insects) was in excess of the supply derived from the inflowing water and from surface absorption, so that anaerobic bacterial activity spoiled the water. Artificial aeration with compressors was tried, but owing to the area and shape of the lake, it was not a success. Considerable growths of Scenedesmus, one of the green algae, appeared at midsummer, and were allowed to go on unchecked, as the reservoir was out of service, and practically devoid of dissolved oxygen at the surface. Scenedesmus happens to be one of the most benign algae, but, candidly, we feared to use copper, thinking it would make bad matters worse. Contrary to expectation, as the growth increased the quality of the surface water steadily improved, apparently due to release of oxygen by the green algae as a by-product of photo-synthesis. The plants had saved the day. Since then we have been able to utilize several of the algae in this manner with marked improvement in the upper waters. In fact, this simple expedient has enabled us to retain the lake in service all summer, skimming off the top layers, whereas otherwise it would have been necessary to put the reservoir out of service. Naturally, not all algae can be employed in this way, but

generally speaking those members of the chlorophyceae which are known not to be producers of foul odors, may be used.

Not infrequently birds assume importance on reservoirs, particularly those which send water directly into service. Swallows nesting around an outlet tower have been known to add colon bacilli to water which was otherwise perfect, thus necessitating a chlorine treatment that would not have been required. Obviously the remedy is to prevent nesting about the outlet works. In Los Angeles we have had several instances where water fowl have carried Peridinium from the brackish sloughs near Wilmington, or perhaps from the open sea, to our distribution reservoirs. This organism is exceedingly interesting and even useful in the ocean, but it is always an unwelcome visitor in reservoirs, because it makes the water rusty red in color, and imparts a most unpleasant odor and taste when the growth finally dies.

Cormorants are also undesirable about a reservoir, first because they may seriously deplete the stock of fish, and second because of their unclean habits. Like swallows, they haunt the outlet towers and sadly deface the structures. It has been found desirable in Los Angeles to drive them off the reservoirs by shooting.

The worst bird offenders, however, are sea gulls and mudhens. In the fall it is a common thing for 10,000 or more gulls to rest on one of our lakes at night, and the amount of guano which they deposit in the water is sufficient to become a matter of real importance. Probably 30 grams per day per bird is a conservative estimate, and when this is multiplied by the immense numbers of birds present it is easy to see how it may affect the quality of the water. Increase in B. coli content is the least serious result, for chlorination may be made to remove these bacteria. The amount of oxygen consumed in the reduction of the fecal matter is great enough seriously to deplete the available reserve, and when this has been done, anaerobic bacterial activity quickly spoils the water. In the Los Angeles reservoir referred to above, we feel confident that the exhaustion of oxygen has been largely due to birds. Moreover, the fertilizing value of the guano stimulates luxuriant growths of algae, for these plants are quite as susceptible to the effects of fertilizers as are the farmers' crops. To be sure, growing algae furnish free oxygen to aid in the reduction of organic pollution, but many types cannot be permitted to grow long enough to accomplish real aid in this way, for they would give rise to their own peculiar bad tastes in the water. Because of the complexity of these actions and reactions, the problem of control

is far from simple, but even here some benefit is to be derived by pitting the activities of plants against those of animals. So far, however, we have obtained our best results by shooting at the birds sufficiently to drive them from the lake.

The control of pollution on an impounding reservoir is at once the most important and most difficult of problems in economic biology. It is well to accentuate the fact that what we desire is *economic* control, for the whole solution of the problem hinges upon economy. If natural purification can be depended upon to accomplish the desired results it would be unwise to spend money to do it artificially. Naturally, gross pollution must be removed regardless of cost, but where adequate storage is afforded and draft is made through a distribution reservoir, too much money must not be spent on the impounding system. Under ordinary conditions it is better practice to regard this branch of biological control as belonging to distribution reservoirs, but of course where one reservoir acts in both capacities, as Sweetwater reservoir, it is necessary to treat the lake as a distribution reservoir and eliminate all possible contamination. This policy has been adopted in the case of Sweetwater, and the company has bought up most of the small holdings around the lake, removing the buildings and holding the land fallow. Continuous chlorination of the effluent is relied upon to provide final protection.

There is one more task which biology may be made to shoulder under some conditions. In the case of a water which is high in temporary hardness, that passes through a large impounding reservoir and subsequently through one or more distribution reservoirs protected by the accepted treatment plants, plankton algae may be made to materially reduce the hardness, perhaps to the entire amount of the temporary hardness. It is well known that these plants are able, after all the free carbonic acid has been removed from water, to attack bicarbonates of calcium or magnesium with the release of half-bound $CO_2$, which they use as food material. The normal carbonates of these bases, which result from such action, are insoluble, and hence removed from the upper layers of water where photosynthesis occurs. At the end of summer such reduction in our Haiwee reservoir has amounted to 30 or more parts per million of total hardness expressed as $CaCO_3$. To make such phenomena of economic value, it would be necessary to foster algal growths all summer, with no draft through the lake, and just before the autumnal overturn, to draw the softer

water from the surface into lower reservoirs. Naturally, conditions making possible this use of biological phenomena will not be found often, but still they do exist. Morena reservoir, on the San Diego system, occurs to me as an example, for draft there is made only once a year, and always after the summer plankton growths have had full opportunity to do their work.

Careful study of the biological factors affecting water under storage will undoubtedly show us many new ways of improving water. The amount of work done by living plants and animals is astonishingly great, and means will be found to direct at least part of these activities for the benefit of man. Perhaps one of the most profitable ways in which small funds can be invested is in detailed and intelligent study of fresh water biology in its economic aspects.

# CALCIUM AND MAGNESIUM HYDRATES AS COAGULATING AGENTS[1]

By Martin E. Flentje[2]

The fact that the hydrates of calcium and magnesium, under certain conditions, are coagulating agents is not new, and no attempt will be made in this report to establish a new theory of coagulation. However, the application of the coagulating powers of these two chemicals to the purification scheme at Oklahoma City gave results that were thought worthy of publication.

The clarifying powers of Mg hydrate are due to the gelatinous form of this compound, which rather closely resembles the floc formed from alum. Lime, because of the setting free of hydroxyl ions, causes the setting in motion of the negatively charged clay particles, which upon striking one another form larger masses. These in time settle. This finds application in the muddy western and southwestern waters, which though high in alkalinity, are more easily settled with alum and lime than with alum alone. Among the smaller plants in Oklahoma using turbid river waters, it is quite common practice to remove excessive turbidity with lime alone, and apparently this is the only really satisfactory method of obtaining a properly clarified effluent.

The water supply of Oklahoma City is obtained from the North Canadian river. It is impounded in a 5½ billion gallon reservoir, this giving a long period of preliminary sedimentation and providing a means of catching and storing the softest water available. The water is aerated, softened with lime, clarified with iron and alum, settled, carbonated with flue gases, filtered and chlorinated. A daily average of approximately 8 million gallons per day is filtered and treated over the year. The water fortunately contains very little non-carbonate hardness, and requires only lime for softening.

Up until February, 1926, just sufficient lime was added to the water to reduce the total alkalinity to 50 p.p.m., at which point

[1] Presented before the Iowa Section meeting, November 4, 1926.

[2] Superintendent of Filtration, Oklahoma City, Okla.

little or no removal of magnesium took place. The use of alum with iron with no removal of magnesium had been found the most economical method of treating the turbid river water which had been used before the present reservoir was put into service. This report deals only with the stored water of the reservoir, and from the time when it was placed in service until the present. The application of the coagulants has always been under laboratory control and has been reported upon. (Spaulding, Chas. H., Laboratory apparatus helps operate filters. Eng. News-Record, 96, No. 16, 644–45, 1926). With the turbid river water, the method that is described below apparently was of no aid in reducing the high coagulant costs. From February on, however, enough lime has been added to give an excess of from 6 to 12 p.p.m., resulting in a precipitation of a part of the magnesium, and a subsequent lowering of the coagulants required. An average of 95 pounds of alum and 294 pounds per million gallons of iron were required in the 8 months prior to February. These quantities were lowered through over-treatment to an average of 39 pounds of alum and 96 pounds of iron per million gallons, from February to the present. (The period of 8 months prior to February is taken for comparison with the latter ones because the reservoir was put into operation at that time and comparable operating conditions prevail over the whole period. This is shown in table 1, figure 1.) The over-treatment of the water required the addition of more lime, but the amount was almost negligible from a cost standpoint, only 67.5 pounds per million gallons being the average required. The extra amount of lime was determined by multiplying the average parts per million reduction in alkalinity for any one month by the average increase in the amount of lime per million gallons required per parts per million reduction in alkalinity. This then was considered part of the coagulant cost together with the lime necessary for the precipitation of the iron. Putting the matter then on a cost basis, the coagulant cost has been lowered from an average of $6.43 to an average of $2.86 per million gallons, a saving of $3.57 per million gallons. This has been plotted and tabulated in table 2 and figure 2. The increase in the parts per million of Mg precipitated is shown in table 3, figure 3, together with the increase in the lime required per parts per million reduction in alkalinity.

That the results obtained with this water are largely due to the coagulating action of the precipitated $Mg(OH)_2$ was shown in the

TABLE 1

*Characteristics of Oklahoma City water*

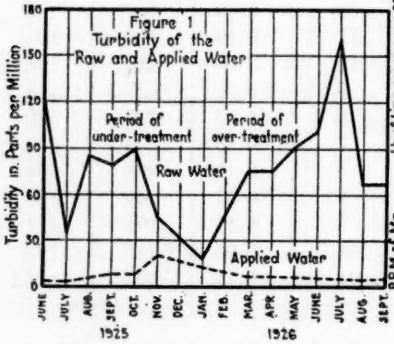
| MONTH | TURBIDITY | | | TOTAL HARDNESS | |
|---|---|---|---|---|---|
| | Raw | Applied | Filtered | Raw | Filtered |
| June | 121 | 4 | 0.08 | 276 | 170 |
| July | 35 | 3 | 0.05 | 280 | 159 |
| August | 85 | 5 | 0.07 | 201 | 123 |
| September | 79 | 8 | 0.14 | 211 | 136 |
| October | 88 | 8 | 0.09 | 202 | 127 |
| November | 45 | 20 | 0.10 | 200 | 125 |
| December | 32 | 17 | 0.10 | 195 | 136 |
| January | 18 | 12 | 0.08 | 212 | 138 |
| February | 44 | 9 | 0.11 | 207 | 117 |
| March | 77 | 6 | 0.12 | 229 | 126 |
| April | 77 | 7 | 0.10 | 230 | 136 |
| May | 90 | 6 | 0.12 | 268 | 154 |
| June | 100 | 6 | 0.07 | 249 | 139 |
| July | 160 | 5 | 0.11 | 194 | 114 |
| August | 66 | 4 | 0.06 | 187 | 102 |
| September | 66 | 5 | 0.13 | 192 | 87 |

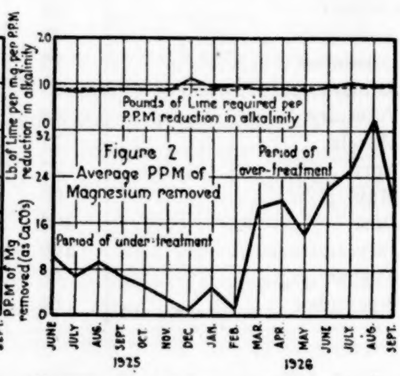
TABLE 2

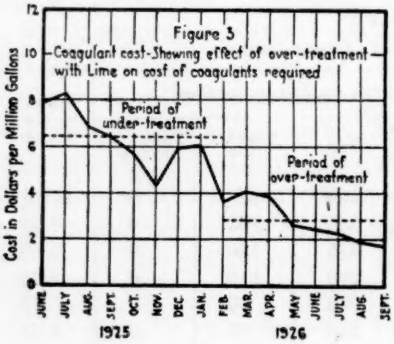
*Amount and cost of coagulant*

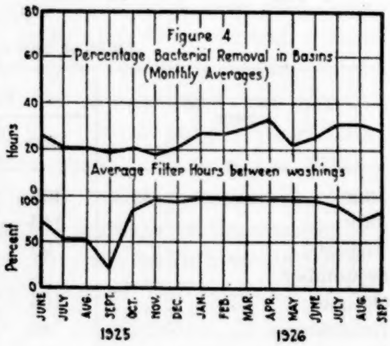
| MONTH | POUNDS PER MILLION GALLONS | | | | COST OF COAGULANTS |
|---|---|---|---|---|---|
| | Alum | Iron | Lime for iron | Lime for excess | |
| June | 105 | 369 | 148 | 0 | $7.81 |
| July | 113 | 388 | 155 | 0 | 8.22 |
| August | 92 | 325 | 130 | 0 | 6.89 |
| September | 98 | 290 | 116 | 0 | 6.43 |
| October | 105 | 239 | 96 | 0 | 5.75 |
| November | 49 | 215 | 86 | 0 | 4.34 |
| December | 91 | 266 | 106 | 0 | 5.92 |
| January | 106 | 261 | 104 | 0 | 6.11 |
| February | 61 | 123 | 49 | 64 | 3.64 |
| March | 48 | 155 | 62 | 77 | 4.02 |
| April | 58 | 131 | 52 | 77 | 3.82 |
| May | 29 | 94 | 38 | 84 | 2.75 |
| June | 24 | 91 | 36 | 75 | 2.55 |
| July | 38 | 69 | 28 | 56 | 2.28 |
| August | 27 | 54 | 22 | 55 | 1.92 |
| September | 30 | 56 | 22 | 52 | 1.89 |

following manner. A number of composite daily samples of raw water were collected and allowed to settle. The clear water was decanted off, leaving the clay in the bottom of the containers. To this then was added distilled water. This gave a suspension of the same clay as in the natural water, with however only a very small amount of dissolved solids. To portions of this suspension were added various concentrations of lime water, the mixture agitated with a mechanical agitator and allowed to settle. To other portions




of the suspension were added equal amounts of a $MgCl_2$ solution, then various concentrations of lime solution. These were then also agitated and allowed to settle. The results are tabulated in table 4, showing that with a precipitation of the Mg, a strong clarifying action takes place. The samples treated with lime alone remain opalescent, very little clarification resulting. This also removes this problem from the hydrogen-ion concentration explanation for optimum results.

Carrying the process still further, it might seem that it would be still cheaper to precipitate more of the magnesium and do the entire clarification in this manner. Some experiments were carried

TABLE 3

*Lime used*

| MONTH | POUNDS PER MILLION GALLONS | | POUNDS LIME USED PER PART PER MILLION REDUCTION IN ALKALINITY | PART PER MILLION Mg REMOVED |
|---|---|---|---|---|
| | Total lime | Lime for reduction in alkalinity | | |
| June | 1,180 | 1,032 | 8.6 | 10 |
| July | 1,243 | 1,088 | 8.1 | 7 |
| August | 948 | 818 | 8.6 | 9 |
| September | 934 | 818 | 8.9 | 7 |
| October | 837 | 741 | 8.8 | 5 |
| November | 936 | 850 | 8.9 | 3 |
| December | 1,151 | 1,045 | 11.4 | 1 |
| January | 1,055 | 951 | 9.5 | 5 |
| February | 1,138 | 1,089 | 10.0 | 2 |
| March | 1,219 | 1,157 | 9.0 | 19 |
| April | 1,205 | 1,153 | 9.0 | 20 |
| May | 1,258 | 1,220 | 8.7 | 14 |
| June | 1,240 | 1,204 | 9.6 | 22 |
| July | 978 | 950 | 10.2 | 25 |
| August | 925 | 903 | 9.8 | 34 |
| September | 872 | 850 | 9.9 | 18 |

TABLE 4

*Effect of $MgCl_2$ on clarification*

| SAMPLE | LIME ADDED | $MgCl_2$ ADDED | CLARIFICATION AND FLOC |
|---|---|---|---|
| | *p.p.m.* | *p.p.m.* | |
| 1 | 20 | 0 | Poor floc; slight |
| 2 | 30 | 0 | Poor floc; slight |
| 3 | 40 | 0 | Poor floc; slight |
| 4 | 50 | 0 | Small floc; slight |
| 5 | 40 | 40 | Good floc; immediate |
| 6 | 50 | 40 | Good floc; immediate |
| 7 | 60 | 40 | Good floc; immediate |

on with this in view and are tabulated in table 5. From this it will be seen that, in order to get a properly clarified effluent, approximately 30 p.p.m. of additional lime would be necessary over that

required to give a slight excess of lime. This amount of lime at 86 cents per 100 pounds would cost slightly over $2.00, or little

TABLE 5

*Effect of lime on clarification*

| SAMPLE | LIME | ALKALINITY | | | MAGNESIUM REMAINING | TURBIDITY | |
|---|---|---|---|---|---|---|---|
| | | T. | P. | C. | | Forty-five minutes settling | Two hours settling |
| | *p.p.m* | | | | | | |
| 1 | 105 | 52 | 21 | | 48 | 60 | 60 |
| 2 | 115 | 54 | 27 | 0 | 39 | 34 | 32 |
| 3 | 125 | 54 | 30 | 6 | 42 | 26 | 24 |
| 4 | 135 | 55 | 36 | 17 | 42 | 13 | 12 |
| 5 | 150 | 57 | 44 | 31 | 35 | 2 | 2 |

Alkalinity, of raw water........................................ 120
Turbidity, of raw water........................................ 75
Magnesium, as $CaCO_3$, p.p.m........................................ 58

TABLE 6

| MONTH | BACTERIAL COUNT ON RAW WATER AT 37.5°C. | BACTERIAL COUNT APPLIED WATER | PER CENT REMOVAL | B. COLI IN APPLIED WATER, PER CENT SAMPLES |
|---|---|---|---|---|
| June | 2,420 | 643 | 73.4 | 30.0 |
| July | 900 | 425 | 52.8 | 10.0 |
| August | 1,640 | 816 | 50.1 | 65.6 |
| September | 1,275 | 940 | 26.4 | 51.7 |
| October | 1,108 | 183 | 83.5 | 64.5 |
| November | 476 | 23 | 95.2 | 36.7 |
| December | 335 | 17 | 94.9 | 9.7 |
| January | 195 | 6 | 96.9 | 22.6 |
| February | 222 | 9 | 96.0 | 21.4 |
| March | 320 | 10 | 96.5 | 22.6 |
| April | 435 | 21 | 95.2 | 17.2 |
| May | 851 | 42 | 95.3 | 25.8 |
| June | 932 | 103 | 89.0 | 19.4 |
| July | 1,540 | 177 | 88.5 | 35.6 |
| August | 700 | 186 | 73.4 | 33.0 |
| September | 1,110 | 195 | 82.5 | 83.0 |

more than the coagulant cost using lime, iron, and alum, during either August or September of this year. Apparently the maximum benefit is to be derived from the removal of between 15 and 20 p.p.m.

of magnesium. The figures above also neglect, in our case, the additional cost of pumping more $CO_2$ for the carbonation of the added lime.

Another advantage in this method of treatment is the added sterilization effect of the free lime. The variation in bacterial removal due to the shorter detention periods during the summer peak loads has been largely done away with. Table 6 and figure 4 show that a consistent bacterial removal of approximately 95 per cent is obtained in the basis at all times. The decrease in the number of positive B. coli tests has not been all that has been hoped for. This is explained by the fact that the free lime concentration has been too low to give a complete sterilization in the detention period available. It has not seemed desirable to seek complete sterilization in the settling basins as the free lime required to do this would throw an additional load on the carbonating equipment, which is slightly inadequate even now. However with the advent of winter, at which time taste troubles due to excess chlorine are more noticeable, it may become desirable to get a more complete sterilization in the basins. This water during cold weather gives noticeable tastes with free chlorine, at concentrations below which sterilization can be relied upon. However, decided attenuation at least, of any pathogenic bacteria must take place under these conditions. Hoover, Houston and others have shown that bacteria of the colon and typhoid group are killed in from five to twenty-four hours when present in water containing $\frac{1}{2}$ to 1 grain of excess lime. The period of detention in the Oklahoma City basins is from eight to ten hours. Some of the results mentioned above are masked somewhat by the results of a few periods of pre-chlorination of the raw water. This has been done at times in an effort at taste control.

Little change in the length of the filter runs has resulted (fig. 4). These results are not exact as at times it was advisable to wash filters every twenty-four hours regardless of the loss of head. At least no reduction in the length of the filter runs has resulted. In the last few months the filters seemed to be losing some of their ability to remove bacteria. This, however, has not been determined as yet.

Algae growth on the basin walls has been greatly inhibited. An interesting phase of this been the noticeable lack of green growth on the walls of the entire basin, except in the carbonating chambers. Here rather abundant growth of the algae has taken place during

the entire summer, due to the removal of the free lime by the $CO_2$ gas.

## SUMMARY

1. The addition of a small amount of lime to the Oklahoma City water over that needed for softening has resulted in considerable saving in coagulant cost.

2. Magnesium hydrate, under certain conditions at least, is an efficient coagulating agent, lowering considerably the treatment cost in a water in which it can be utilized.

3. The presence of free lime in the treated water makes possible—

*a.* An attractive method of taste control during cold weather, in that less chlorine is necessary.

*b.* The production of a softer water because of the smaller amount of carbonate hardness introduced during clarification.

*c.* The inhibition of algae growth on basin walls.

Acknowledgement is made to C. E. Bretz, Superintendent of Water Department, Oklahoma City, for his co-operation in obtaining and for his permission to present the above data.

# CITY WATER SUPPLIES IN ARKANSAS

By Harrison Hale[1]

Examination has been made of 92 samples of water from 80 cities and towns of Arkansas. These city supplies varied widely in total dissolved solids. Hot Springs and Mena have only 40 parts per million each, while in three towns of the state the total dissolved solids exceed 1000 p.p.m. This is the limit set for drinking water in standards adopted by the United States Treasury Department, June 20, 1925, as recommended by the Advisory Committee on Official Water Standards.[2] Eighteen towns have less than 100 p.p.m., the average being 268.

Water is generally clear and free from odor and any considerable amount of color. Only eight towns show a turbidity as high as 10 p.p.m. as prescribed in the standards; four others have 5 p.p.m. of turbidity.

No samples approach the 250 p.p.m. limit set for sulfate, the highest being 134. Only two others are as much as 100, the average for all samples being 20.2 p.p.m.

Magnesium, likewise, is uniformly low, only 3 samples being as much as 20 p.p.m., the highest being 31. The limit for magnesium is placed at 100, while the average was 5.4 p.p.m.

In chloride content there is great variation, running from 1.8 to 576.5 p.p.m. Five supplies exceed the limit of 250. Although the average is 44 p.p.m., there are 40 towns with less than 10, the average being greatly raised by a few high results.

Oxides of iron and aluminum were determined together. It is interesting that bauxite, located near the source of more than 90 per cent of the total aluminum ore produced in the United States,[3] showed the highest, 20.5 p.p.m., the next being 11.8. Only 2 others exceeded 7, the average being 3.2 p.p.m.

[1] Head of Chemistry Department, University of Arkansas, Fayetteville, Ark.; Consulting Chemist, Water Department, Fort Smith, Ark.

[2] Reprint No. 1029 from the Public Health Reports, April 10, 1925 (pp. 693–721).

[3] United States Geological Survey Report, 1924.

For silica, 3 samples exceeded 40 p.p.m., the average being 19.7 p.p.m.

The amount of scale varied widely, being less than 0.2 pound per 1000 gallons at Mena and at Marked Tree and more than 3 pounds in two other places, the average being 1.03 pounds. Pounds of hard scale per 1000 gallons show less variation, averaging 0.367 pound.

Scale and hard scale were calculated in accordance with the formulas given by Herman Stabler's Industrial Application of Water Analyses in United States Geological Survey Water Supply Paper 274 (1911) pp. 175–177. Other determinations were in accordance with the Standard Methods of the American Public Health Association (1923).

There is a general relationship between the mineral content and the geographical distribution. At times, however, waters from sources not far apart show striking differences. This is due to the fact that one may be a surface water and the other from a well.

So far as the sources are known they are in this order: (1) wells, (2) springs, (3) rivers or creeks, (4) lakes. Fifty-eight per cent of those reported are from wells.

In the larger cities and towns filtration and a germicide are generally used, usually chlorination. In some chlorination only is used while in a majority treatment is not yet given.

These results together with data on pumpage and purification equipment are to be published as a bulletin of the Engineering Experiment Station, University of Arkansas. This will contain also the results of bacteriological tests made by the Laboratory of the State Board of Health.

# SOCIETY AFFAIRS

### CALIFORNIA SECTION

The convention, held at San Diego, October 28, 29 and 30, 1926, was particularly fortunate in encountering bright, warm, balmy Southern California weather which did much to enhance the pleasure and enjoyment of those attending and especially the ladies who were entertained by various excursions while the men were in the convention sessions.

The attendance greatly exceeded the fondest hopes of the committees in charge, and the San Diego Hotel, designated as convention headquarters, could only shelter a part of the members and visitors, so many were quartered at the U. S. Grand and other hotels.

The business dinner held on Thursday evening in the Pompeiian Room of the San Diego Hotel was attended by 240 delegates. The dinner dance held Friday evening by the manufacturers had a total attendance of 383 members, guests and ladies.

The convention meetings were held in the American Legion Hall in Balboa Park, a permanent building preserved from the San Diego Fair of 1915. A large, well lighted hall furnished ample room to house the exhibits of fifty manufacturers, which were exceedingly well arranged and complete and proved a most instructive and valuable adjunct to the convention. The convention meetings were held in the east end of the hall which, suitably screened by curtains made an ideal comfortable assembly room with good acoustic properties.

Invitations had been extended to all members of adjoining states, and in response, there were in attendance, members from Canada, Oregon, Idaho, Utah, Colorado and Arizona. The total registration was 383, classified as follows: Active members—86; Associate members—106; Waterworks men guests—101; and ladies—90.

The program was carried out in accordance with the program below with President C. B. Jackson presiding. The papers were well prepared, but unfortunately were too lengthy to allow time for proper consideration and discussion.

The election of officers to serve for the ensuing year were as follows: Chairman, S. B. Morris; Vice-Chairman, J. J. Ryland; Secretary-Treasurer, Paul E. Magerstadt; Executive Committee, P. Dieterich and J. Burt.

San Jose was unanimously chosen as the meeting place for the convention of 1927, with the San Jose Water Company acting as host.

An address by William Mulholland, Chief Engineer of the Los Angeles Water Department, was easily the banner feature of the convention. The subject of his address was the rapidly growing needs of the City of Los Angeles and the proposed $200,000,000 development of the Colorado River to bring water 231 miles for the City's relief.

On Friday evening the manufacturers were host at a dinner dance at which 383 members and guests were in attendance. After dinner the famous Orpheus Quartette of Los Angeles entertained with several selections. A clever cowboy monologist also favored with several pleasing offerings. An enjoyable dance followed until the early hours of the morning.

On Saturday morning an interesting trip over a portion of the San Diego water system was made as guests of the City of San Diego. A lunch was served at the Lower Otay Filter Plant. The trip was well arranged, both interesting and instructive, and proved a fitting finale to a successful convention.

THURSDAY, OCTOBER 28, 1926

*Forenoon*

General Get-together Registration and Review of Exhibits.

*Afternoon*

Address of Welcome. By Hon. John L. Bacon, Mayor of San Diego.

1. Description of the Impounding Works of the San Diego Water System. By R. C. Wueste.
2. The Biological Control of Impounding Reservoirs. By Dr. Carl Wilson.
3. Report on Water Meter Maintenance Methods. By J. H. Fagg.
4. Five-minute papers and discussions.

*Evening*

Informal Dinner, Pompeiian Room, The San Diego Hotel.
Business Meeting.
Report of Retiring Officers.

Report of Committees.
Election of New Officers.
Selection of next place of meeting.

The Colorado River Project. By William Mulholland.

Moving Picture—From Mine to Consumer. By courtesy of American Brass Company.

FRIDAY, OCTOBER 29, 1926

*Forenoon*

1. Progress in Electrolytic Chlorination at Sacramento Filtration Plant. By Harry N. Jenks.
   Paper to be read by Ralph Stevenson.
   Discussion by Charles Lundelius.
2. Corrosion Problems of a Water Supply System and Methods of Protection. By E. B. Stewart.
3. Equitable Charges for Automatic Sprinkler Connections. By William Cartwright.

*Afternoon*

1. Underground Waters and Pumping Therefrom. By George W. Trauger.
2. Water Consumption for Various Purposes in Terms of Depth and Area. By Charles Lee.
3. Iodine in Drinking Water. By George E. Ebright and C. G. Gillespie.

*Evening*

Dinner Dance—Informal, in the Pompeiian Room, The San Diego Hotel, as guests of the Exhibitors. Selections by "Orpheus Four."

P. E. MAGERSTADT,
*Secretary.*

# ABSTRACTS OF WATER WORKS LITERATURE

## Frank Hannan

**Key:** American Journal of Public Health, **12:** 1, 16, January, 1922. The figure 12 refers to the volume, 1 to the number of the issue, and 16 to the page of the Journal.

**The Future Development of the Metropolitan Area Surrounding San Francisco Bay.**—Charles H. Lee. Bulletin of the Seismological Society of America, **16:** 2, 81, June, 1926. The purpose of this paper is to picture the essential facts and problems relating to the present and future metropolitan area of San Francisco Bay, and to outline what might be done to reduce future hazards to life and property from earthquake and earthquake fires. The included land capable of intensive development covers 876,300 acres, with an ultimate population of between 5 and 6 million, the true value of all taxable property at least $12,000,000,000, of which 50 per cent will be more or less destructible. Future demand for water will be at least 1075 million gallons daily, requiring, in addition to 250 m.g. from local sources the equivalent to full development proposed for Hetch Hetchy, Mokelumne, and Eel River projects. Sacramento-San Joaquin River at head of Bay may also be drawn upon. Reduction of hazard from fire and earthquake may be attained by guiding development on the basis of definite community and regional plans. Following items suggested: Systematic establishment of open spaces in form of broad thoroughfares, highways, parks, etc., to act as firebreaks and places of refuge; preservation of adequate and efficient ferry system in conjunction with trans-Bay bridge or tubes when built; adoption of building codes designed to promote earthquake-proof construction and use of fire resistant materials; adoption of definite program to be followed by electric and gas utilities at the occurrence of an earthquake; increasing amount of local storage capacity in water distribution systems of different communities; utilizing all feasible reservoir sites in Bay region for reserve storage, and, as far as possible, interconnecting all reservoirs and distribution systems, with ultimate aim of completely circling the Bay with transmission pipe line or conduit capable of drawing water from any major reservoirs in case of emergency; establishment of plan of organization, local and general, for handling water problems of future metropolitan area. The interconnection of water systems, although limited somewhat by relative elevations of reservoirs, is quite feasible, and, in the event of an earthquake at any point in the Bay region, might be of inestimable value. Earthquakes have independent origin on either side of the Bay, and major shocks have never been known to occur simultaneously at different points in the Bay region. The probabilities are that damage to a water system serving one unit of the Bay region would not occur at a time when systems serving other units were out of commission. Each independent

water system in the Bay region as it is built and extended will utilize the feasible reservoir sites within its immediate area. By interconnection, the supply held by such reservoirs may be made more or less available to other systems. By careful study certain sites might be made available for holding reserve supplies which could be fed into an interconnected series of distribution systems at times of emergency.—*A. W. Blohm.*

**Strengthening and Indurating Concrete with Sulfur.** W. H. Kobbé. Eng. News-Rec., **96**: 940-2, 1926. The strength of concrete can be considerably increased by impregnating with sulfur. The treatment process consists of immersing the concrete in a bath of S maintained at 130 to 150°C., for several hours. Standard tensile briquets of cement mortar which ordinarily break at 150 pounds are increased in strength to over 1000 pounds and as high as 2000 pounds per square inch by this treatment, and strength under compression is similarly increased. Water absorption is usually reduced to less than 2 to 3 per cent.—*R. E. Thompson* (*Courtesy Chem. Abst.*).

**Underwater Piledriving and Cofferdam Sealing.** John C. Pritchard. Eng. News-Rec., **96**: 930-3, June 10, 1926. Illustrated description of driving precast reinforced concrete piles for St. Louis intake structure at Howard Bend, and of sealing cofferdam with concrete. Piles, which were cast on job, were 48 feet long and 16½ inches in diameter and were driven to rock inside cofferdam, 538 being used in all. Bottom of cofferdam was then sealed with layer of concrete 5 feet thick poured under water by means of tremie. Total of 3050 cubic yards of concrete were poured in 5 days' continuous operation. After dewatering, reinforced concrete bottom 5 feet thick was poured on top of concrete seal. For high-service pit, 68-foot piles were employed.—*R. E. Thompson.*

**Earth Dam Fails by Shrinkage.** Eng. News-Rec., **96**: 942, June 10, 1926. Brief illustrated description of failure of small earth dam of Loch Alpine Development Company, Delhi, Mich. Construction of dam extended into winter of 1925-1926 and shrinkage had only begun when sharp freezing weather set in. Top and side of embankment froze, forming shell over soft clay below, which continued to shrink and settle, leaving porous condition under frozen shell which resulted in failure during flood following thaw. Recommended that upstream face be lined with stone after damage has been repaired.—*R. E. Thompson.*

**Water Works Type Condensers.** Wynkoop Kiersted, Jr. Eng. News-Rec., **96**: 952-3, June 10, 1926. Advantages of water works type condensers are simplicity of operation and absence of pump auxiliaries attending use of standard type. Without correct design of structural details advantages may be offset by high frictional resistance to passage of water. Two instances of this are cited.—*R. E. Thompson.*

**Laying Intake Through Earth Dike Under Service.** Eng. News-Rec., **96**: 1010-4, June 24, 1926. Illustrated description of installation of 90-inch rein-

forced-concrete intake at Denver, Colo., which will deliver water from Marston Lake, a 6000-m.g. reservoir, to new 70-m.g.d. mechanical filtration plant. Lake, which has average diameter of 1 mile, has an earth embankment extending around most of perimeter. Intake was laid through 40-foot dike and into lake a distance of about ¼ mile to avoid algae growths, terminating in conical screen on upturned elbow. Cofferdams constructed through dike for pipe and on shore for traveling-screen house, are described and illustrated. As pipe line must act as siphon when lake level is low, airtightness was necessity. This was effected by molding welded steel cylinders into concrete during manufacture of pipe and calking joints with lead. Subaqueous pipes beyond siphon section were only bolted together.—*R. E. Thompson.*

**Home-Made Lift Replaces Sidings in Tunnel Construction.** Eng. News-Rec., 96: 954, June 10, 1926. Brief illustrated description of air lift being used by San Joaquin Light and Power Corporation in driving tunnels of Balch hydro-electric project in California instead of switch and siding for setting out empty muck cars awaiting return at heading.—*R. E. Thompson.*

**Handling a Large Water Flow in the Moffat Tunnel.** C. A. Betts. Eng. News-Rec., 96: 985, June 17, 1926. Measures adopted during construction of Moffat tunnel when 3000-gallon per minute water course was cut by main heading described briefly.—*R. E. Thompson.*

**El Paso, Tex.** Eng. News-Rec., 96: 980–1, June 17, 1926. New 2-to 3-m.g. circular reinforced-concrete reservoir will increase reservoir storage capacity to 25.5 m.g. Water is pumped by motor-driven centrifugals from 6 wells averaging 1.6 m.g.d. each. Additional wells pumped by air increase total supply to 16 m.g.d., which may be further augmented by 2.5 m.g.d. from surface well used only in fire emergency. Centrifugal pumps cost 1.5 cents per 1000 gallons to operate.—*R. E. Thompson.*

**A Problem in Plant Layout in Saturated Sand.** Eng. News-Rec., 96: 1016–7, June 24, 1926. Illustrated description of laying of foundation of new Jamaica sewage treatment plant, New York City, in wet sand, which was effected by means of circular caisson 82 feet in diameter and 63 feet deep.—*R. E. Thompson.*

**Reduction of Mud Balls in Rapid Sand Filters.** August V. Graf. Eng. News-Rec., 96: 1031–2, June 24, 1926. Brief description of method employed at Chain of Rocks filtration plant, St. Louis, Mo., for disintegrating mud balls, which consists of jetting sand from one end of filter to opposite end with hydraulic ejector while wash water is being applied. Wash water used during 5-hour period employed for jetting sand in each filter is about 1430 gallons per square foot of filter area. Cleaning filters by this method once every 6 months has reduced mud balls very considerably and also removed part of coating of sand grains due to softening.—*R. E. Thompson.*

**Formulas for Calculating the Total Hardness of Water (from Conductivity).** B. MARKUS. Vers. Meded. Betrefende de Volksgezondheid, July 1926, 715–23. Usual formula for calculating hardness in German degrees, D, from conductivity is:

$$D = \frac{K_{18} \times 10^6 - 3\ Cl}{30}$$

where $Cl$ = mgm. per liter of chlorine as chloride. Fleischer's improved formula is:

$$D = \frac{L - 3\ Cl - 20\ K(F_s - F_k)}{F_s}$$

where $L = K_{18} \times 10^6$; $Cl$ as before; $K$ = temporary hardness; and $F_s$ and $F_k$ are average conductivities for 1 degree sulfate hardness and 1 degree temporary hardness respectively. Samples in which $L$ is greater than 850 are diluted with distilled water until $L$ is less than 200, in which case (group V below) $Ld = K_{18} \times 10^6$ for distilled water used in dilution, $v$ = degree of dilution and $l$ = value assumed by $L$ in diluted sample. The following table shows values of $F_s$ and $F_k$ for various values of $L$.

| | $L = K_{18} \times 10^6$ | $F_k$ | $F_s$ | HARDNESS |
|---|---|---|---|---|
| I | 1–300 | 29 | 40 | $\frac{L - 3\ Cl - 20 + 11\ K}{40}$ |
| II | 300–400 | 26 | 38 | $\frac{L - 3\ Cl - 20 + 12\ K}{38}$ |
| III | 400–600 | 24 | 37 | $\frac{L - 3\ Cl - 20 + 13\ K}{37}$ |
| IV | 600–850 | 22 | 36 | $\frac{L - 3\ Cl - 20 + 14\ K}{36}$ |
| V | 850 or over (diluted) | 29 | 40 | $\frac{vl - 3\ Cl - 20 - vLd + 11\ K}{40}$ |

Ninety-four Dutch waters were tested and greatest differences between analyses and formulas were +1.2° to −4.2° for ordinary and +1.6° to −2.3° for Fleischer's. Average was −0.69° for former and −0.37° for latter.—*R. E. Thompson.*

**Cement Specifications Changed by Missouri Highway Commission.** F. V. REAGEL. Eng. News-Rec., 96: 657, 1926. To meet conditions in Missouri, two changes were made in cement specifications for 1926, namely, (1) a minimum

tensile strength of 225 pounds at 7 days was specified, and (2) a provision was added to the effect that fluctuations in setting time causing finishing difficulties in field would be held cause for rejection.—*R. E. Thompson* (*Courtesy Chem. Abst.*).

**New Water Pumping and Filtration Plant, Hannibal, Mo.** M. P. Hatcher. Eng. News-Rec., **96**: 727–8, 1926. Additions to the water works of Hannibal, consisting of an 11-million gallon per day electrically-driven pumping station and a 6-million gallon per day mechanical filtration plant, are described. The supply, which is drawn from the Mississippi River, was formerly only coagulated, settled and chlorinated. Modification of settling basin provides storage capacity of 8 million gallons each for raw and filtered water. Lime and alum will only be applied during approximately 2 months of the year, when the turbidity is high. The average water consumption is 2.25 million gallons per day by a population of approximately 19,300.—*R. E. Thompson* (*Courtesy Chem. Abst.*).

**Methods for the Determination of Oxygen Dissolved in Water in Presence of Nitrous Acid.** G. Alsterberg. Biochem. Z., **159**: 36–47, 1925. From Chem. Abst., **20**: 790, March 10, 1926. Hydrazoic acid is used to eliminate disturbing effect of nitrite in determination of dissolved oxygen. ($N_2O_3 + 2HN_3 = 2N_2O + 2N_2 + H_2O$.) Solutions containing alkali or mineral acid must be used to prevent the reaction $2NaN_3 + 2I = 2NaI + 3N_2$ from taking place. Remainder of determination is same as that of Winkler. In presence of small quantities of nitrite, hydrazoic acid may be added after precipitated manganese dioxide is dissolved in sulfuric acid. Reagent has following composition: 3 g. sodium hydroxide, 20 potassium iodide and 0.5 g. sodium azide in 100 cc. of solution. Amount used is 1 cc.—*R. E. Thompson.*

**Determination of Oxygen Dissolved in Water in Presence of Nitrite.** M. E. Stas. Chem. Weekblad, **22**: 584–5, 1925; cf. C. A., **7**: 4026. From Chem. Abst., **20**: 790, March 10, 1926. Alsterberg's method (cf. preceding abstract) gives accurate results provided the water is treated with $NaN_3$ before liberation of iodine. The nitrite content of sewage waters does not exceed 8 mgm. per liter, so 10 mgm. $NaN_3$ is sufficient.—*R. E. Thompson.*

**Rapid Testing Methods for Rust-Preventive Paints.** H. Wolff. Farbe und Lack, 1925, 576–7; Farben-Ztg., **31**: 579–80, 1925. From Chem. Abst., **20**: 831, March 10, 1926. Accelerated tests do not yet with certainty determine most essential properties, durability and rust prevention, of metal-protective paints. Review of accelerated tests is given, with discussion.—*R. E. Thompson.*

**Recreational Use of San Diego's Water-Supply Reservoirs.** R. C. Wueste. Eng. News-Rec., **97**: 386–8, 1926. The recreational use of reservoirs in San Diego, which includes fishing and waterfowl hunting, is described. The supply is obtained from water courses which are dry except during the rainy season, the policy being to provide storage reservoir capacity of 2 to 6000 million

gallons per 1 million gallons per day safe net yield, the cost of these projects being $500,000 to $1,000,000 per million gallons per day safe net yield. During 1925, receipts from recreational use were $24,440, 75 per cent of which was net profit. The supply is filtered through pressure filters and chlorinated at rate of 2.5 pounds per million gallons. The B. coli index of the treated water during 1925 was zero.—*R. E. Thompson* (*Courtesy Chem. Abst.*).

**Report, Corporation of Madras Water Analysis Laboratory, 1924–5.** S. V. Ganapati. 31 pp. Tabulations of analytical results are given and discussed. The slow sand filters give erratic results and a system of sedimentation, rapid filtration and, when necessary, chlorination, has been recommended. When the raw water is clear considerable time is required for formation of filtering film on filters and as a result the bacteriological results are poor. Under these conditions the formation of an artificial film by addition of alum during the first day of the filter run and subsequently at 7 to 10-day intervals, as required, has resulted in improved efficiency. Difficulties have been experienced with white filamentous growths in the filter chambers, filtered water conduits and reservoirs, which give rise to odor of hydrogen sulfide, particularly on decay. Chlorination and treatment with potassium permanganate have failed to remedy the condition, which is most acute during periods of high temperature. The organism causing the trouble has not been identified.—*R. E. Thompson.*

**American Society for Testing Materials, Tentative Standards, 1925.**—Separate, 876 pp. (1925); cf. C. A., **19**: 3331. From Chem. Abst., **20**: 954, March 20, 1926.—*R. E. Thompson.*

**Reconstruction of the Albany Water Filters.** Allen Hazen. Eng. News-Rec., **97**: 380–6, 1926. Recent additions and repairs to Albany filtration plant are described and illustrated in detail. The essential additions were a new coagulation basin and new aërators. The water, which is drawn from the polluted Hudson River, is aërated at inlet to coagulation basin after addition of coagulant, passed through pre-filters at rate of 75–115 million gallons per acre per day, aërated again, passed through slow sand filters at rate of 6 million gallons per acre per day, and finally chlorinated. During 1925 the average color was reduced from 55 to 8. The average number of bacteria in the raw water was 67,500 per cubic centimeter, and in the coagulation basin, pre-filter and final filter effluents, 4,950, 300 and 5 respectively.—*R. E. Thompson* (*Courtesy Chem. Abst.*).

**Pulling 1200 Feet of 18-inch Cast-Iron Pipe Across Burrard Inlet, Vancouver, B. C.** C. Brakenridge. Eng. News-Rec., **97**: 366–9, September 2, 1926. Contract Record, **40**: 811–4, August 25, 1926. Illustrated description of installation of first of four 18-inch flexible-joint cast-iron submerged mains across Burrard Inlet at the Second Narrows, Vancouver, being a section of third conduit extending from intake on Seymour Creek to Little Mountain reservoir near center of Greater Vancouver Water District. Main conduit is 13 miles in length and 36 inches in diameter, constructed of $\frac{5}{16}$ to $\frac{7}{16}$-inch steel. Crossing

consists of 1200 feet of completely submerged course and 1200 feet of tidal flat. Pipe for crossing was assembled on chute and pulled or pushed across by cables and pulleys operated by donkey engines. Pipe was actually in motion a little over 1 hour, spread over period of 4 days.—*R. E. Thompson.*

**Adjustable Leg on Trestle Aids Pipe Lowering on Side Hill.** Eng. News-Rec., 97: 374, September 2, 1926. During laying of 26-inch steel pipe line of Marin Municipal Water District in California, it was necessary to support pipe above trench during welding and then lower considerable lengths into trench. Trestle with adjustable leg developed to facilitate the work is described.—*R. E. Thompson.*

**The Chemical and Physical Mechanism of Rusting and Corrosion.** O. Bauer. Gas- u. Wasserfach, **68**: 683–7, 704–7, 715–9, 1925. From Chem. Abst., **20**: 355, February 10, 1926. General review and discussion.—*R. E. Thompson.*

**The Present Status of Chlorine Gas Therapy.** E. B. Vedder. Ann. Clin. Med., **4**: 21–9, 1925. From Chem. Abst., **20**: 451, February 10, 1926. Optimum concentration is 0.015 mg. per liter. Best length of exposure is 1 hour.—*R. E. Thompson.*

**Chemical and Physical Studies on Mineral, Particularly Iron, Metabolism.** Oskar Baudisch and L. A. Welo. Naturwissenschaften, **13**: 749–55, 1925. From Chem. Abst., **20**: 438, February 10, 1926. Clear mineral water from Franzensbad, Czechoslovakia (0.0178 gr. ferrous iron per kilogram) was sealed in evacuated flasks. On exposure to light the water became opalescent and turbid, whereas in the dark it remained unchanged. Precipitate formation runs parallel with disappearance of catalytic power of the mineral water; light accelerates the aging. The iron at first is present in the "active" form, described by Baudisch in previous papers. Biological properties of mineral waters are discussed from point of view of Werner's coördination theory and the action of light.—*R. E. Thompson.*

**The Salinity of Artesian Waters of Lower and Middle Belgium. (Second Note).** J. Delecourt. Ann. soc. geol. Belgique, **48**: B41–B52, 1925. Cf. C. A., **19**: 231. From Chem. Abst., **20**: 465, February 10, 1926. Description of chemical properties of main flows of Belgium and France.—*R. E. Thompson.*

**Supply of Bathing and Drinking Water on Plantation.** A. W. A. Jacometti. Arch. Suikerind., **33**: 1010–7, 1925. From Chem. Abst., **20**: 465, February 10, 1926. Description of Jewell installation in Java.—*R. E. Thompson.*

**Studies of the Horizontal and Vertical Regions of Activity of Surface Water, Streams and Springs.** Franz Hocheder. Gas-u. Wasserfach, **68**: 575–8, 590–2, 610–3, 625–7, 1925. From Chem. Abst., **20**: 465, February 10, 1926. Lengthy mathematical discussion with many diagrams, tables, etc.—*R. E. Thompson.*

**Water Supply for Textile Mills.**—C. L. Hubbard. Textile World, **68**: 2891–4· 1925. From Chem. Abst., **20**: 466, February 10, 1926. Water clarification and softening for textile mills is discussed.—*R. E. Thompson.*

**Amounts of Soap and Builder Necessary to Soften Water of Different Degrees of Hardness.** H. B. Robbins, H. J. MacMillan and L. W. Bosart. Ind. Eng. Chem., **18**: 27-9 1926. From Chem. Abst., **20**: 466, February 10, 1926. Description of most economical procedure to be followed where hard water must be used in laundry work. General conclusion is that soda ash should be added with agitation and a little time allowed for the reaction to take place before addition of soap. Soda ash required varies with hardness of water.—*R. E. Thompson.*

**The "OMS" Purifier, a New Clarification Process for Industrial Waste Water.** Otto Mohr. Apparatebau, **37**: 304, 1925. From Chem. Abst., **20**: 466, February 10, 1926. An improved Dorr thickener.—*R. E. Thompson.*

**The Behavior of Magnesium Chloride in Boiler Feed Water.** J. H. Vogel. Kali, **19**: 394–6, 1925. From Chem. Abst., **20**: 467, February 10, 1926. Controversial review. Deleterious effects of magnesium chloride in boilers are not caused by splitting of hydrochloric acid, but by other phenomena (cf. Vogel, Die Abwasser aus der Kaliindustrie, Berlin, 1913, p. 250).—*R. E. Thompson.*

**The Corrosion of Iron Pipe Lines.** Gustav Wiegand. Gas- u. Wasserfach, **68**: 731-4, 1925. From Chem. Abst., **20**: 467, February 10, 1926. Conditions in German cities described and preventive measures discussed.—*R. E. Thompson.*

**Physical Properties of Boiler Scale.** G. Paris. Chimie et industrie, Special Number, 138–42, September, 1925. From Chem. Abst., **20**: 467, February 10, 1926. Description of various types of scale, their constituents and mode of formation.—*R. E. Thompson.*

**Protection of Steam Boilers Against Scale and Corrosion.** R. Caillol. Chaleur et industrie, **6**: 357-62, 419-24, 469-74, 1925. From Chem. Abst., **20**: 467, February 10, 1926. Review and discussion of relative merits and disadvantages of various processes of feed-water purification and of protecting inside of boilers against scaling and corrosion.—*R. E. Thompson.*

**The Relation Between Drinking Water and Goiter.** W. von Gonzenbach. Gas-u. Wasserfach, **68**: 667–71, 1925. From Chem. Abst., **20**: 467, February 10, 1926. General discussion of distribution of goiter in Central Europe.—*R. E. Thompson.*

**Measurement of the Rate of Flow of Fluids by the Rotameter.** W. H. Simmons and F. C. Sutton. Ind. Chemist, **1**: 473–4, 1925. From Chem. Abst.,

20: 523, February 20, 1926. The rotameter consists of a top-shaped float contained in a tapered glass tube. The liquid to be measured in passing through the tapered tube lifts and spins the float. The spinning prevents float touching walls; hence there is no friction, and height of float adjusts itself to flow which passes through annular space between float and wall of tapered tube, which can be readily calibrated for any liquid. Temperature changes in liquids introduce scarcely any error. Three types are illustrated.—*R. E. Thompson.*

**The Principles for the Calculations of Venturi-Meters.** OTTO VON KÁLMÁN. Siemens Z., **5**: 473–8, 1925. From Chem. Abst., **20**: 522, February 20, 1926. Description of Venturimeters from Die Wassermesser Fabrik der Siemens und Halske A. G., and the theory and calculations for measuring of water, steam, gas and air.—*R. E. Thompson.*

**The Decimal Dropping Bottle as a Technical Titration Apparatus.** C. BLACHER. Chem-Ztg., **49**: 959–61, 1925. From Chem. Abst., **20**: 522 February 20, 1926, The nipple of the "normal dropping bottle" is made of proper size to give drops of 0.1 cc. of water solutions. Its advantages for rapid titrations, especially for determination of hardness in boiler feed water, are enumerated. Twelve references included. (Cf. WINTER, Apparatebau, 1923, 161.)—*R. E. Thompson.*

**Change in Concentration of Electrolytic Impurities.** M. DEKAY THOMPSON. Chem. Met. Eng., **32**: 700, 1925. From Chem. Abst., **20**: 551, February 20, 1926. Equation is derived which gives variation in concentration of an impurity in an electrolyte with time, amount of impurity removed and introduction of impurity being constant for each unit of time. Equation permits calculation of time required to attain equilibrium concentration of impurity, and it is applied to accumulation of impurities in boiler water.—*R. E. Thompson.*

**Action of Sodium Chloride Solutions on Ferrous Metals.** RENÉ GIRARD. Compt. rend., **181**: 552–5, 1925. From Chem. Abst., **20**: 573, February 20, 1926. Tests on corrosion of cast iron and steel immersed in 20-gram-per-liter sodium chloride solutions showed that: when solution is not aërated both iron and steel lose weight steadily and at approximately the same rates; in aërated solution steel loses weight somewhat more slowly than in non-aërated solution, while the cast iron oxidation products adhere to metal and form protective coating.—*R. E. Thompson.*

**Modern Quick-Hardening Cements.** C. T. STEPHENS. Commonwealth Engineer, **13**: 89–91, 1925. From Chem. Abst., **20**: 651, February 20, 1926. Short general discussion of high-alumina cements and rapid-hardening portland cements. Differences in composition, manufacture and strength of resulting products stated. Few estimates upon cost and information concerning use of these products in buildings and concrete pipes, included.—*R. E. Thompson.*

**Description of Public Water Supplies of Rhode Island.** Stephen De M. Gage. Jour. New Eng. Water Works Assoc., **40:** 2, 117, June, 1926. Thirty-six public water supplies in R. I. are listed and the following data given for each;—location, population supplied, date of introduction, by whom operated, source of supply, form of distribution, source of power, consumption, and general quality of water supplied.—*W. U. Gallaher.*

**New Water Supply System at Tampa, Florida.** N. S. Hill, Jr. Jour. New Eng. Water Works Assoc., **40:** 2, 128, June, 1926. Rapid growth of Tampa made new supply imperative. Former well supply was highly saline and very hard. Hillsborough River, selected as new source, has dry weather flow estimated at 50 million gallons per day during dry months and 600 to 700 million gallons per day during rainy season. Hardness and color of raw water vary from 200 p.p.m. and 25 p.p.m., respectively, during dry season, to 25 p.p.m. and 200 p.p.m., respectively, during rainy season. Experimental filter plant was operated from August, 1924, to February, 1925. Improvements include intake, combined low and high lift pumping station, treatment plant for softening, decolorizing, recarbonating, and filtering, 30-inch cast-iron force main some three miles long, and three one-half million gallon elevated tanks. Concrete intake chamber in center of channel is 31 feet high in 25 feet of water and has three 48-inch sluice gates protected by 1½-inch wrought iron bar screens. It is connected to suction and screen well by 36-inch cast-iron conduit 225 feet long. Pump suctions are protected by ¼-inch copper wire removable screens. Three 200 h.p. B. & W. water tube boilers using fuel oil (or coal) furnish steam at 175 pounds pressure with 100 degrees superheat. Two 12.5- and one 6.5-m.g.d. De Laval centrifugal pumps operating against 30 feet head and driven by De Laval steam turbines are installed for low lift purposes, and two 10- and one 5- m.g.d. of the same type operating against 2200 feet head have been installed for high lift pumping. Three Wheeler surface condensers, each handling the exhaust from one low-lift and one high-lift pump, use water from the low-lift discharge for condensing. Condenser water is wasted. Two 350 g.p.m. motor driven pumps furnish wash water. The treatment plant has 12 to 15 m.g.d. capacity. Decolorization is aided by addition of sulfurous acid. Water is softened with lime and soda during the dry season. Mixing tanks, eight each for lime and alum, are equipped with bronze propellers operated by 1 h.p. motors. Two tanks are used in series. There are two lime settling basins each with 1 million gallon capacity and 4 hours detention and three decolorizing basins each with ¾ million gallon capacity and 3 hours detention. They may be operated in series or parallel. First half of basins have a simple sludge removal system consisting of 6-inch vitrified pipe underdrains with tees pointing upward the tops even with the basin floor. Open end is closed with vitrified plug with 1 inch orifice in centre. They are designed to stand a small pressure for back washing. Chemicals are carried in solution by concrete troughs from six dry feed Gauntt type machines. Sulfur is burned in two Schutte and Koerting burners of 35 pounds per hour capacity. Gas is cooled, then absorbed in water spray. Vitrified orifice tank is used to proportion solution which is added with alum. Carbon dioxide equipment furnished by Carbondale-New York Company consists of 1200

pounds daily capacity coke oven, scrubber, and compressor. Gas is added through 1½-inch grid in baffled compartment. Filter plant is unusually attractive architectually and is well ventilated and lighted; pipe gallery is unobstructed by pipes etc. Eight 1.5 to 1.75 m.g.d. filters have combined an area of 4800 square feet and contain 18¾ inches gravel which varies from 2½- to $\frac{1}{16}$-inch, and 30 inches of sand with effective size of 0.4 mm. and uniformity coefficient 1.6. Wash troughs are concrete. Filters have special strainer system of half-round cast-iron pipes raised ½ inch from the floor to form a long horizontal orifice on each side of pipe. Holes are bored in top to release air. Steel wash tank, capacity 100,000 gallons, is controlled by Ross pressure-reducing valve. Covered filter reservoir with ½ million gallons capacity has been built. Control of pumping station and filter plant is centralized and convenient. A 30-inch cast iron main leads treated water to city where it divides into two 24-inch parallel pipes one-half mile apart. Three one-half million gallon elevated steel tanks in different parts of city reduce peak load at plant. An old 3.5 million gallon concrete reservoir is used for fire service; two motor driven 5 m.g.d. pumps are installed nearby one of which starts pumping water from the reservoir into distribution system as soon as an alarm comes in. Entire system is designed to permit extensions to be made without trouble.—*W. U. Gallaher.*

**Rainfall in New England.** X. H. Goodnough. Jour. New Eng. Water Works Assoc., **40:** 2, 178, June, 1926. A complete record, with description of gages used, of monthly and yearly rainfall at 337 stations in Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, and adjoining Canada and New York, from the earliest records to 1925 inclusive—*W. U Gallaher.*

**The Operation of the Massachusetts "Water Lien" Law.** Jour. New Eng. Water Works Assoc., **40:** 2, 161, June, 1926. Ten questions on the law are stated and answered. The law itself is stated and examples given of forms used in connection therewith.—*W. U. Gallaher.*

**Report of Committee on Legislative Matters in Massachusetts.** Jour. New Eng. Water Works Assoc., **40:** 2,175, June, 1926. Past session of legislature extended the privilege to water companies of obtaining emergency supplies, lengthened the term of bonds for large mains (16-inch or over) to 25 years, and term of bonds for intermediate pipes (6- to 16-inch) to 15 years.—*W. U. Gallaher.*

**Data on Zeolite Water Softeners.** T. J. Ess. Power Plant Eng., **30:** 16, 888, August 15, 1926. Short description of zeolite softening process. Formulae are given for calculating quantity of zeolite required, area of filter, salt needed for regeneration, etc. Zeolite softened waters may be used in boilers although they contain approximately the same amount of dissolved mineral as before treatment. When nearly run down, zeolite will still remove permanent hardness after it has ceased to remove temporary hardness. Water for boilers of high rating with hardness over 15 grains should have a prepara-

tory treatment with lime and soda before final softening with zeolites.—*W. U. Gallaher.*

**Interpretation of Boiler Water Analyses.** D. C. CARMICHAEL. Power Plant Eng., **30: 17, 943,** September 1, 1926. Boiler waters after soda treatment contain sodium chloride, sodium carbonate, sodium hydroxide, sodium sulfate calcium carbonate, and organic matter. Conversion of sodium carbonate to sodium hydroxide depends greatly on the organic matter, the more of which is present the less hydroxide will be formed. Sodium formate and sodium acetate formed in reactions may suppress formation of hydroxide. Sodium chloride is formed by decomposition of chlorides and sodium sulfate from calcium and magnesium sulfates. Priming is proportional to sodium chloride present. Determinations of chloride, pH, and alkalinity, give rough method for judging proper treatment.—*W. U. Gallaher.*

## NEW BOOKS

**Chlorination and Chlorine Absorption of Water.** Dr. A. MASSINK. Chemisch Weekblad, **23**: 29, 1926. Chlorination of water supplies has been introduced of recent years into Holland and is now coming into extensive use. Two systems are in vogue; the indirect, which is normal practice in America, in which the chlorine reaches main bulk of water to be treated in form of an aqueous solution, and the direct, in which chlorine is applied as a gas in a state of very fine division. The main purpose of present paper is to bring to the notice of those concerned the papers of ABEL WOLMAN in which the fundamental principle of the dependence of the optimum chlorine dosage upon the chlorine absorption of the water was firmly established. In connection therewith is added an instructive review of certain methods in use for determination (*a*) of free chlorine, namely, FROBOESE'S, OLSZEWSKI'S, ELLMS and HAUSER'S and the MUIR and HALE modification thereof, and WINKLER'S, and (*b*) of chlorine absorption, namely, WOLMAN'S, FROBOESE'S, BRUNS'S, and OLSZEWSKI'S. Among many valuable references to the literature, both European and American, such recent American papers as those of BUSWELL and BORUFF and of OLE FORSBERG are discussed. While it was found that OLSZEWSKI'S method of using benzidine and o-tolidin at the pH of approximately 5.6, at which the blue meriquinonoid color is most intense and least fugitive, is capable of yielding good results, yet the preference is given to MUIR and HALE modification of ELLMS and HAUSER method in which is developed, owing to the greater acidity, the yellow holoquinonoid color which is both less fugitive and less closely dependent upon pH control. OLSZEWSKI'S automatic free chlorine indicator is mentioned with approval.—*Frank Hannan.*

**The ABC of Hydrogen Ion Control.** W. A. TAYLOR. Catalog of LaMotte Chemical Products Company. This catalog gives a treatise on the colorimetric determination of hydrogen ion control as well as listing materials and equipment. It contains a non-technical discussion of hydrogen ion concentration and pH values, a technical discussion for the chemist, bacteriologist, engineer, etc., and the application of pH control to over twenty different types

of work. In water purification pH control has been widely adopted. Coagulation takes place at a definite pH value, which is different for different waters. By determining the optimum pH value for a given water, which can be done by a few simple tests, the smallest amount of alum necessary to give the best and quickest floc is used at all times and no alum is wasted. The use of alum or acid tends to decrease the pH, and it is in many cases necessary to add alkali after coagulation to prevent corrosion of the distributing system. pH control is also of great value in the softening process, whether lime and soda or artificial softeners are used. The pH value of the brine solution has a marked effect on the efficiency of regeneration of zeolites.—*A. W. Blohm.*